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WATER RESOURCES OF THE NIAGARA FRONTIER AND THE WELLAND RIVER DRAINAGE BASIN

PREPARED FOR
THE ONTARIO MINISTRY OF THE
ENVIRONMENT

PREPARED BY
GARTNER LEE LIMITED

GLL 87132

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SUMMARY

Surface and ground water resources in the Niagara Frontier and the Welland River drainage basin were inventoried to provide a framework for future studies as part of the Ontario Ministry of the Environment's contribution to the Niagara River Toxics Management Plan and the Remedial Action Plan for the Niagara River. Gartner Lee Limited was contracted by the MOE to provide the inventory based on a study of existing information. No field work was undertaken. The study area comprises an area of approximately 1608 km^2 within the Niagara Peninsula of southern Ontario.

The main physiographic features are two north-facing, east-west bedrock cuestas formed at the contact between rock formations (the Niagara and Onondaga Escarpments). The two escarpments separate the study into three plains; the physiographic region of the Lake Iroquois Plain between Lake Ontario in the north and the 50+ m high Niagara Escarpment; the physiographic region of the Haldimand Clay Plain between the two escarpments; and an area of bedrock plain between the 10+ m high Onondaga Escarpment and Lake Erie to the south. The Haldimand Clay Plain underlies the Welland River drainage basin which comprises the western half of the study area. Elevations range from about 76 m ASL at Lake Ontario in the northg to the highest elevation of about 255 m ASL on top of the Fonthill Kame, a circular flat topped hill about 6 km in diameter on the north central divide of the Welland River basin. The ground elevation then declines to about 175 m ASL at Lake Erie in the south.

The climate is moderated by the presence of Lakes Ontario and Erie. Mean daily air temperatures of about 9° C occur along their shores and slightly lower temperatures are found inland along the axis of the Niagara Peninsula. Mean annual precipitation generally increases southward from about 850 mm at Lake Ontario to about 1000 mm near Lake Erie.

The bedrock consists of gently southward dipping ($<1^\circ$) sedimentary carbonate and shale rocks of Paleozoic age interbedded with some sandstone. The rocks are exposed on the bedrock surface as east-west trending bands. Two bedrock cuestas have formed where hard carbonate rocks overlie softer, easily eroded, shale rocks. These form the Niagara and Onondaga Escarpments where they are exposed at ground surface. A veneer of glacial debris caps the rock over most of the remaining area comprised of four generally fine-grained major Quaternary units from youngest to oldest, as follows:

- upper glaciolacustrine
- Halton Till
- lower glaciolacustrine
- lower (Wentworth) till

Two major granular deposits are located at the Fonthill Kame and the buried St. Davids Gorge. The Fonthill Kame formed at the edge of the glacial lake which deposited the upper glaciolacustrine unit. The buried St. Davids Gorge is an abandoned bedrock channel similar to the present-day Niagara River but naturally infilled with a variety of gravels, sands, glacial tills, silts and clays that date back to Middle Wisconsinan times.

Four hydrostratigraphic units have been identified as:

- overburden aquifer comprised of post glacial and the glacial Fonthill Kame deposits
- overburden aquitard comprised of the four fine-grained glacial and glaciolacustrine units
- bedrock aquifer comprised of the basal granular deposits and the high-permeability weathered bedrock
- bedrock aquitard comprised of the lower permeability bedrock below the weathered zone.

The majority of the water wells are completed in the bedrock aquifer. Areas of high yields in the upper part of the bedrock are reported throughout the study area. High yielding wells in the overburden are generally completed in basal granular materials overlying, and hydraulically connected to the bedrock. Some shallow overburden wells are completed in the near-surface overburden aquifer at Fonthill and in the vicinity of the buried St. Davids Gorge. Ground water levels indicate a cyclical pattern of annual peaks in the spring corresponding to maximum ground water recharge, and annual lows in the late summer/fall reflecting ground water depletion by vegetation and evaporation. Flowing wells are reported in the vicinity of the buried St. Davids Gorge, along the Onondaga Escarpment near Lake Erie, and in the Pelham area northwest of Fonthill.

Ground water divides generally coincide with surface water divides and ground water movement in the bedrock aquifer is towards Lake Ontario in the north; Lake Erie in the south; and the Welland and Niagara Rivers in the central and eastern parts of the study area, respectively. Information on ground water movement in the underlying bedrock aquitard is limited. Very high hydraulic heads, tens of metres above ground surface, have been reported at a depth of 50 m near the Niagara River. These heads would act as a barrier to vertical ground water movement. However, below this depth large vertical gradients occur above the Queenston Formation indicating a strong potential for downward movement of ground water.

Natural ground water quality in the overburden aquifer is generally acceptable for drinking water, but the areal distribution of the aquifer is limited to the vicinity of Niagara Falls, the buried St. Davids Gorge, and the Fonthill Kame. The quality of the bedrock aquifer is generally poor due to a high salts content. Slow ground water movement results in chemical dissolution with the adsorbed chloride and sulphate salts during circulation in the bedrock. A progression to high chloride concentration in ground water was observed in the bedrock aquitard. Bicarbonate waters appear to be present only in those areas where more rapid ground water movement occurs, such as in the overburden aquifer. Sodium, hardness, sulphate, and iron consistently exceed the Ontario Ministry of the Environment's Drinking Water Objectives.

The areas where permeable overburden materials or bedrock is within 10 m of the ground surface are considered to be the most susceptible to ground water contamination. These areas are generally found in the southeastern part of the study area. Here there is a widespread use of the bedrock as a source of domestic water supply. Ground water in the overburden aquifer in the vicinity of Niagara Falls, St. Davids, and Fonthill is also highly susceptible to contamination because contaminants are likely to move to depth, both as a result of the moderate to high relief and deeper water tables in these areas, and the absence of confining surficial deposits to protect the aquifer. The bulk of the study area is comprised of relatively impermeable fine-grained glacial materials at surface that will inhibit infiltration to any significant depth.

Parts of three major watersheds comprise the study area:

- Lake Ontario drainage
- Lake Erie drainage
- Niagara River drainage including the Welland River

The Lake Ontario drainage portion is restricted to the northern part of the study area where a series of streams issue from the face of the Niagara Escarpment and drain northward to Lake Ontario. The Welland Ship Canal is the most recent of a series of canals to provide a water transportation link through a series of locks between Lake Erie at about 175 m ASL to Lake Ontario at 76 m ASL. The Lake Erie drainage system is restricted to a narrow band of land along the north shore of Lake Erie where small streams drain southward to the lake from the Onondaga Escarpment. The Niagara River tributaries, including the Welland River, are characterized by poor drainage on a relatively flat plain that slopes gently (at about 1 m/km) eastward from the Hamilton/Mount Hope area to the Niagara River. A well-developed dendritic pattern is evident in the headwater regions of the Welland River where gradients approach 10 m/km.

Detailed streamflow information is available only for the Welland Ship Canal, the Welland River, and the Niagara River. Zero flows are often noted in the small streams draining to Lakes Ontario and Erie. Streamflows in the Welland River are complex because of several diversions, two inverted syphons (beneath the old Welland Canal and new Welland Ship Canal) and the operation of both the Niagara hydroelectric generating stations and the Niagara River Control Structure. Because of hydroelectric diversions, the lower section of the Welland River flows westward (upstream) from Chippawa at the Niagara River to West Montrose. An average of 593 m^3/s or about 10% of the long term average flow in the Niagara River is diverted at West Montrose to the Queenston-Chippawa Power Canal for power generation purposes at Queenston. The low channel gradient in the Welland River and reversed flows in this lower reach (know locally as Chippawa Creek) create backwater conditions that extend approximately 65 km upstream in the Welland River west of the Power Canal. Magnitude of the flows above the backwater effects ranged from 0.05 m^3/s in July, 1985 to 13.7 m^3 in November, 1985. An analysis of low flow data from 1962 to 1981 (for June to December data) indicated both seven-day low flows (7Q20) and duration flows of zero. On the average, for 42 days in every year the natural flow in the Welland River drops to 0.001 m^3/s or less. Extreme low flows in the Niagara River tributaries occur annually during the months of June, July, and August. Average flows in the Welland Ship Canal range from 226 to 241 m^3/s and in the Niagara River flows average 5663 m^3/s. Approximately 20 m^3/s is added to the Welland River from the Welland Canals for flow augmentation purposes that are necessary to assimilate waste discharges to the Welland River, and to provide a circulation in the old Welland Canal.

Based on the examination of 16 conventional parameters, water quality in the Welland Ship Canal is better than that in the Welland River because higher quality Lake Erie water feeds the Canal. Niagara River water quality is also better than that of the Welland River based on these same 16 parameters because Lake Erie water is the source. Phosphorous, bacteriological parameters, copper and phenols in the Welland River are detected at levels exceeding the Ontario Ministry of the Environment's Provincial Water Quality Objectives. Several stretches of the Welland River have specific water quality problems due to industrial and urban runoff.

A water balance calculation was made using the six-year period from 1981 to 1986. Evapotranspiration was estimated and the water surplus was apportioned into surface runoff and infiltration into the ground water system. Total infiltration over the 1608 km^2 study area was then computed to be about 4 m^3/s based on 75 mm/a of ground water recharge. This compares to; 1.7 m^3/s for the water treatment facility for the City of Niagara Falls; or to a flow of about 5692 m^3/s in the Niagara River at Queenston.

Total water withdrawals under MOE permit is about 3.2 m^3/s of which about 10% (0.32 m^3/s) is ground water used for mainly industrial cooling and as process water.

Only limited information is available on toxic organic parameters. Expansion of the parameter list at selected monitoring stations as well as more precise flow determination may be required to assess surface water impacts. Water for irrigation has not been addressed. More data would improve the accuracy of determining the infiltration rates and ground water movement in the overburden, the bedrock aquifer, and in the bedrock aquitard below. These data are required to provide reliable predictions on potential contaminant movement.

The major water resources problems are related to poor natural ground and surface water quality. Quantity problems exist only in isolated areas and are related to dewatering, irrigation, and flooding. Ground water shortage also exists in areas where there is no aquifer present which can be tapped.

1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

The Ontario Ministry of the Environment identified the need for a water resources inventory in the Niagara Peninsula as part of the Ministry's contribution to the Niagara River Toxics Management Plan. The purpose of the inventory is to provide a framework so that future studies can assess and quantify the impact of toxic chemical loadings to the Niagara River.

The study was divided into two phases covering the following geographic areas of the Niagara Peninsula:

- Phase 1: The area bounded by Lake Ontario, the Canada-United States border, Lake Erie, and the Welland Canal system (Niagara Frontier)
- Phase 2: The Welland River Drainage Basin upstream of the Welland Canal system.

This inventory was structured using a format similar to that of the Ontario Ministry of the Environment's previous program of water resources inventory evaluations. It is based on a study of existing information and data compilations reported elsewhere. No field work was undertaken. The report deals with the overburden and bedrock stratigraphy, reviews the major aquifers, and provides discussion on their hydrogeologic properties. Water quality data, for surface and ground waters, ground water level fluctuations, water use, and withdrawals are discussed. The report deals mainly with general hydrogeologic and surface water conditions in the basin and does not address specific situations on a local scale.

1.2 LOCATION

The study area comprises approximately 1608 km^2 (Figure 1). Parts of the Regional Municipalities of Niagara, Hamilton-Wentworth, and Haldimand-Norfolk are included. The study area is divided into two phases for the purposes of presenting data on maps (in map pocket) but the entire area is treated as a single unit in the following discussions.

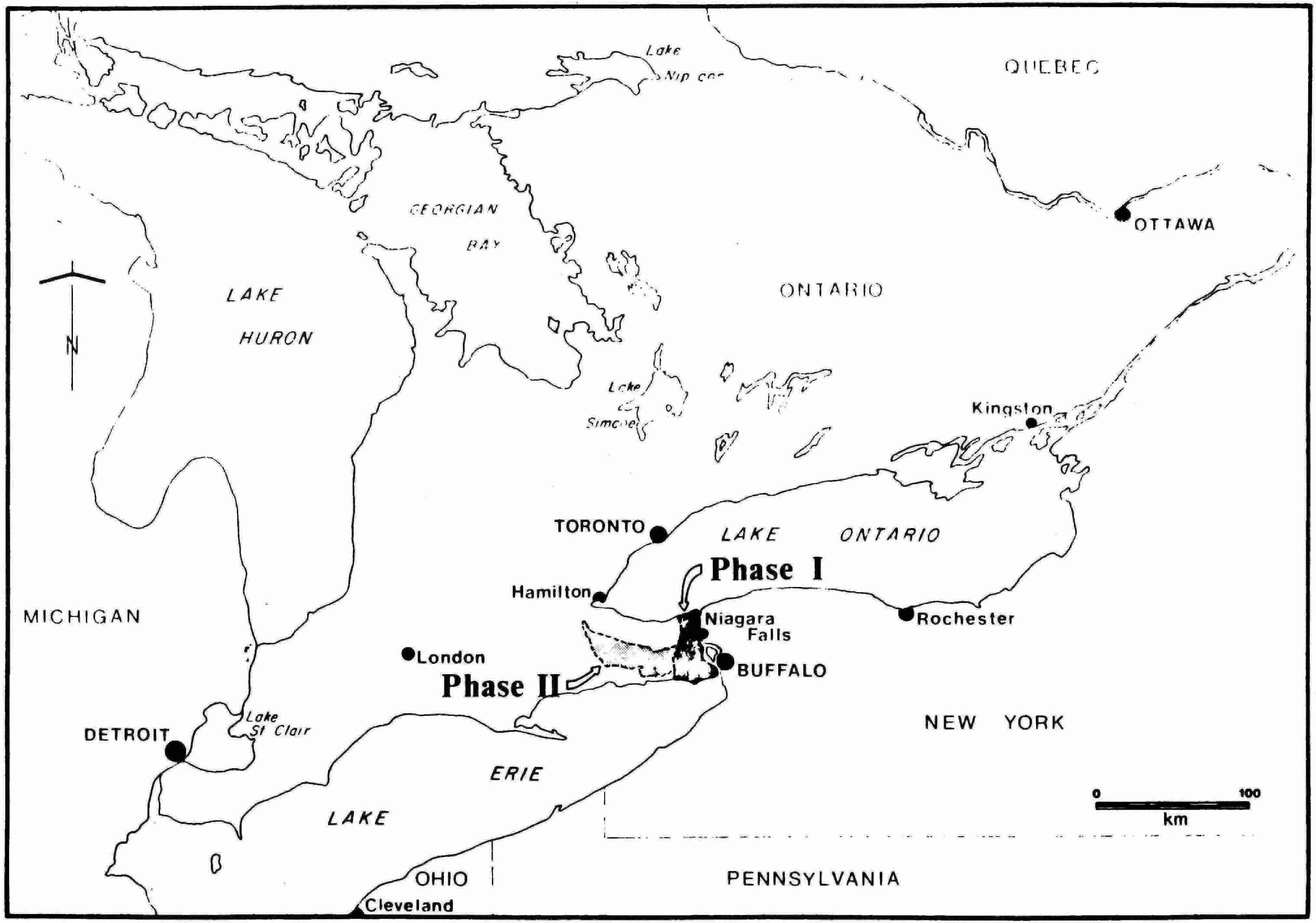


Figure 1 - Location and Extent of Niagara Area Study

Major urban centres include the Cities of Niagara Falls, Port Colborne, Welland; the Towns of Fort Erie, Niagara-on-the-Lake; and the communities of Thorold South, Chippawa, Ridgeway, Crystal Beach, Thunder Bay, and Fonthill. The combined population of these centres is approximately 170 000. Much of the area to the west of Welland is rural in character. The Welland River flows for an approximate length of 132 km through the study area, from a headwaters area south of Hamilton to its mouth at the Niagara River near Chippawa.

2.0 GEOGRAPHY

2.1 PHYSIOGRAPHY AND TOPOGRAPHY

Two of the main physiographic features in the area, the Niagara and Onondaga Escarpments, are north-facing bedrock cuestas formed at the contact between rock formations. The Niagara Escarpment exhibits more than 50 m relief in the Niagara area. It is approximately 5 to 10 km south of, and parallel to the Lake Ontario Shoreline. The Onondaga Escarpment is located on the south side of the Niagara Peninsula, about 6 to 8 km north of the Lake Erie shoreline. This escarpment seldom has more than 10 m of surface relief and is exposed intermittently along its length. Much of this feature is masked by the accumulation of younger sediments.

The two escarpments separate the Niagara Peninsula into three plains (Figure 2): The physiographic region of the Iroquois Plain between Lake Ontario and the base of the Niagara Escarpment; the physiographic region of the Haldimand Clay Plain between the two escarpments; and an area of bedrock plain between the Onondaga Escarpment and Lake Erie.

The Lake Iroquois Plain is the bottom of a former proglacial lake which existed in the Lake Ontario basin during the final stages of deglaciation in the area. The plain consists of patches of lacustrine sand, silt, and clay overlying the eroded surface of the Halton clayey-silt till. This plain is flat and slopes gently northward from 107 m ASL at the Lake Iroquois shoreline north of the Niagara Escarpment to 76 m ASL at Lake Ontario to the north.

The Haldimand Clay Plain is the largest physiographic region in the Niagara Peninsula and underlies almost the entire Welland River drainage basin. The plain overlies a major east-west bedrock depression which has been infilled with glacial and glaciolacustrine clay and silt. Local relief on the plain is generally limited to a few metres (Figures 3 and 4 in map pocket). Several small moraines within this area exhibit minor local relief. The height of land in the vicinity of the City of Niagara Falls at an elevation of about 205 m ASL, is due to the presence of the Niagara Falls Moraine.

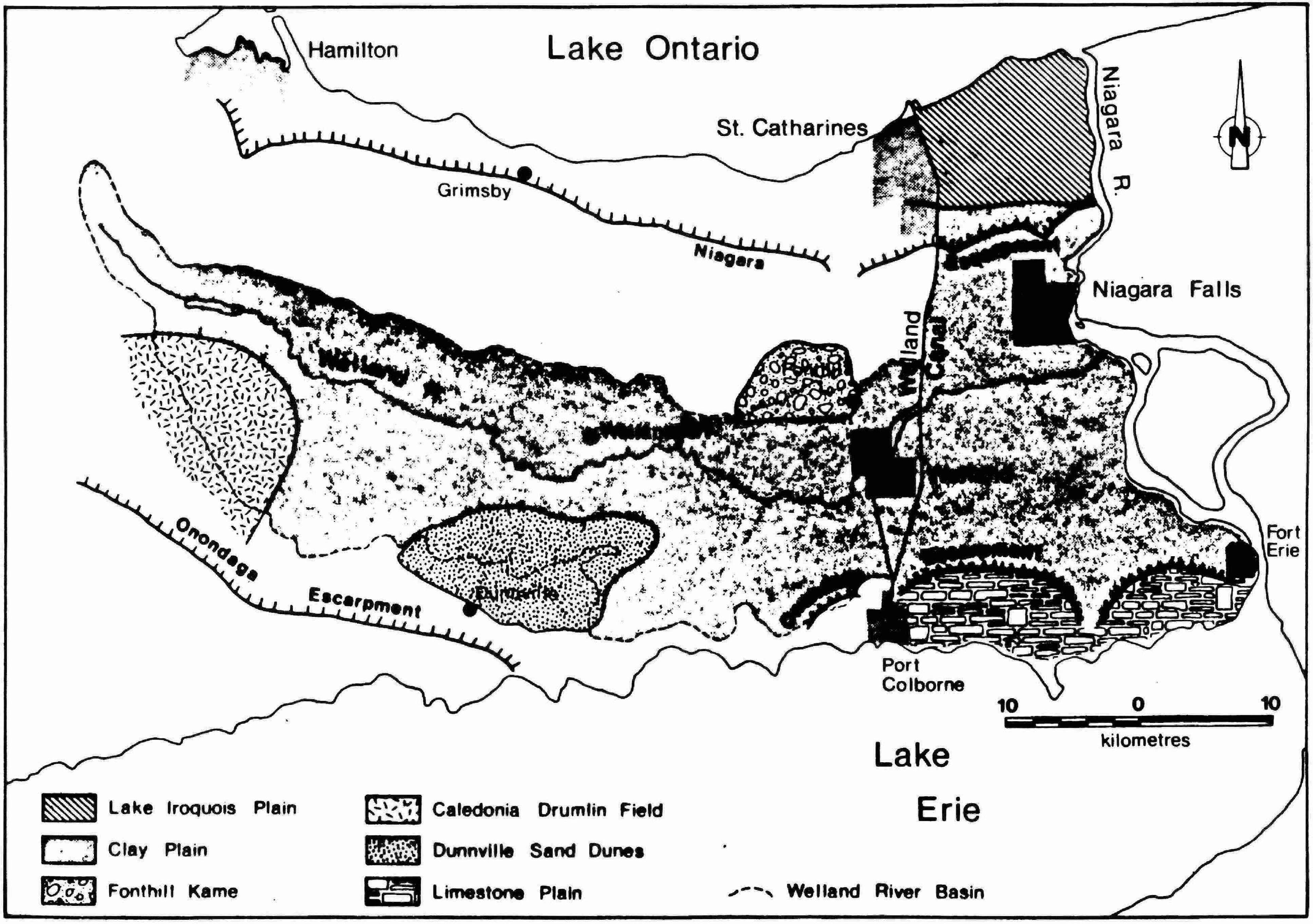


Figure 2 - Physiographic Features of the Niagara Area

The bedrock plain located south of the Onondaga Escarpment consists of significant areas of exposed bedrock with a thin veneer of clayey silt till or glaciolacustrine sediment. Several metres of relief are due to small moraines, beach shorelines, or irregularities in the bedrock surface. Elevations range from approximately 175 m ASL at Lake Erie to 200 m ASL at Ridgemount on the edge of the Escarpment.

The Fonthill Kame is a major topographic feature situated south of the Niagara Escarpment and rising about 60 m above the Haldimand Clay Plain. This feature is a large, nearly circular flat-topped hill composed of silt, sand, gravel, and till measuring approximately 6 km in diameter and reaching the highest elevation in the study area at 255 m ASL (Figure 4 in map pocket). The southern half of this feature is located within the Welland River drainage basin.

2.2 DRAINAGE

Surface water drainage in the study area includes parts of three major watersheds.

- Lake Ontario
- Lake Erie drainage
- Niagara River drainage including the Welland River

The Lake Ontario drainage system is restricted to the area north of the Niagara Escarpment and a small band along the banks of the Welland Canals (Figure 3 in map pocket). Small streams issue from the escarpment face, draining northward into Lake Ontario.

The Lake Erie drainage system is limited to a narrow band of land along the north shore of Lake Erie, south of the Onondaga Escarpment (Figure 3 in map pocket). Minor streams flowing southward to Lake Erie drain this area.

The Niagara River drainage system comprises the Welland River drainage basin primarily, with some minor drainage by small eastward flowing streams immediately adjacent to the northward flowing Niagara River. Water flows from Lake Erie to Lake Ontario via either the Niagara River or the man-made Welland Ship Canal.

Further details on drainage, are provided in Section 5.0.

2.3 CLIMATE

The climate of the study area is influenced and moderated by the presence of Lakes Erie and Ontario. A total of 15 meteorological stations with long term periods of record are available in the vicinity of the study area (Environment Canada, 1982). Temperature and precipitation data have been abstracted and are presented in Table 1.

The long-term meteorological data indicate mean daily air temperatures of about 9° C near Lakes Ontario and Erie, and the Niagara River. Lower temperatures occur inland along the axis of the Niagara Peninsula (Figure 5). A general warming trend is indicated from west to east across the study area ranging from a mean daily temperature of about 7.5° C in the headwater area of the Welland River to about 9° C in the vicinity of the Niagara River. Mean annual precipitation generally increases southward across the study area ranging from about 850 mm in the north part of the study area near Lake Ontario to about 1000 mm in the southern part of the study area near Lake Erie (Figure 6).

STATION	PERIOD OF RECORD	ELEVATION (m)	MEAN ANNUAL PRECIPITATION (mm)	MEAN DAILY TEMPERATURE (°C)
Caledonia	1931 - 1966	206	913.3	7.6
Dunnville (OWRC)	1962 - *	175	905.4	8.0
Fort Erie	1972 - *	180	995.0	8.6
Grimsby	1944 - 1985	93	875.9	9.0
Grimsby (Rock Chapel)	1916 - 1966	198	927.7	7.6
Hamilton A	1973 - *	237	824.0	7.4
Niagara Falls	1965 - *	183	942.3	8.9
Niagara Falls (Ont. Hydro)	1942 - 1972	198	929.0	8.4
Port Colborne	1964 - *	175	985.2	8.6
Port Dalhousie	1957 - *	91	837.2	8.8
Ridgeville	1969 - *	236	860.5	8.2
St. Catharines A	1973 - *	98	818.5	8.9
St. Catharines (Power Glen)	1965 - *	122	835.8	8.6
Virgil Brights	1965 - 1978	99	816.2	9.2
Welland	1975 - *	175	938.0	8.6

* operational presently

Table 1 Selected Meteorlogical Data in the Vicinity of the Niagara Area Study

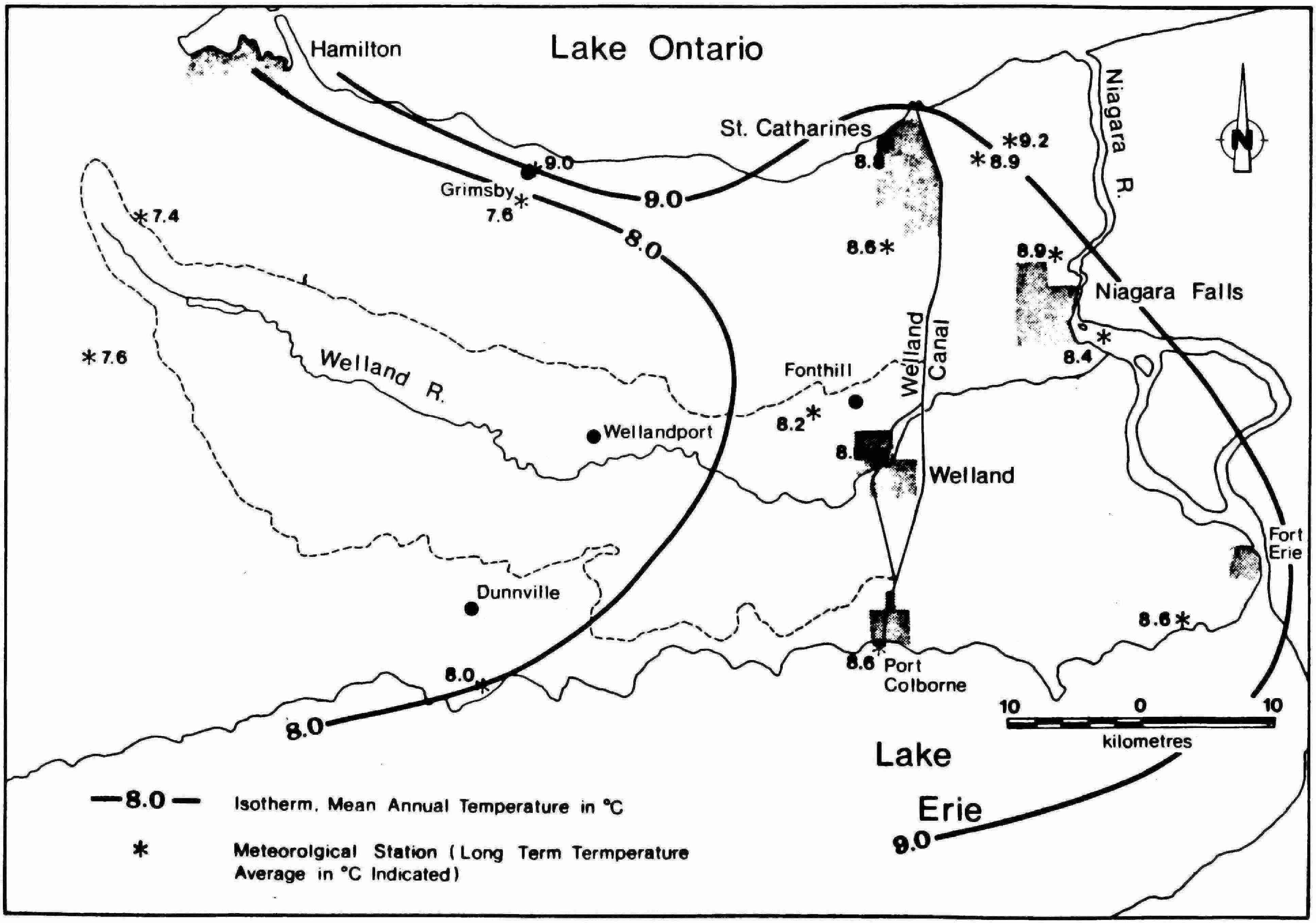


Figure 5 - Mean Daily Temperatures in the Niagara Area

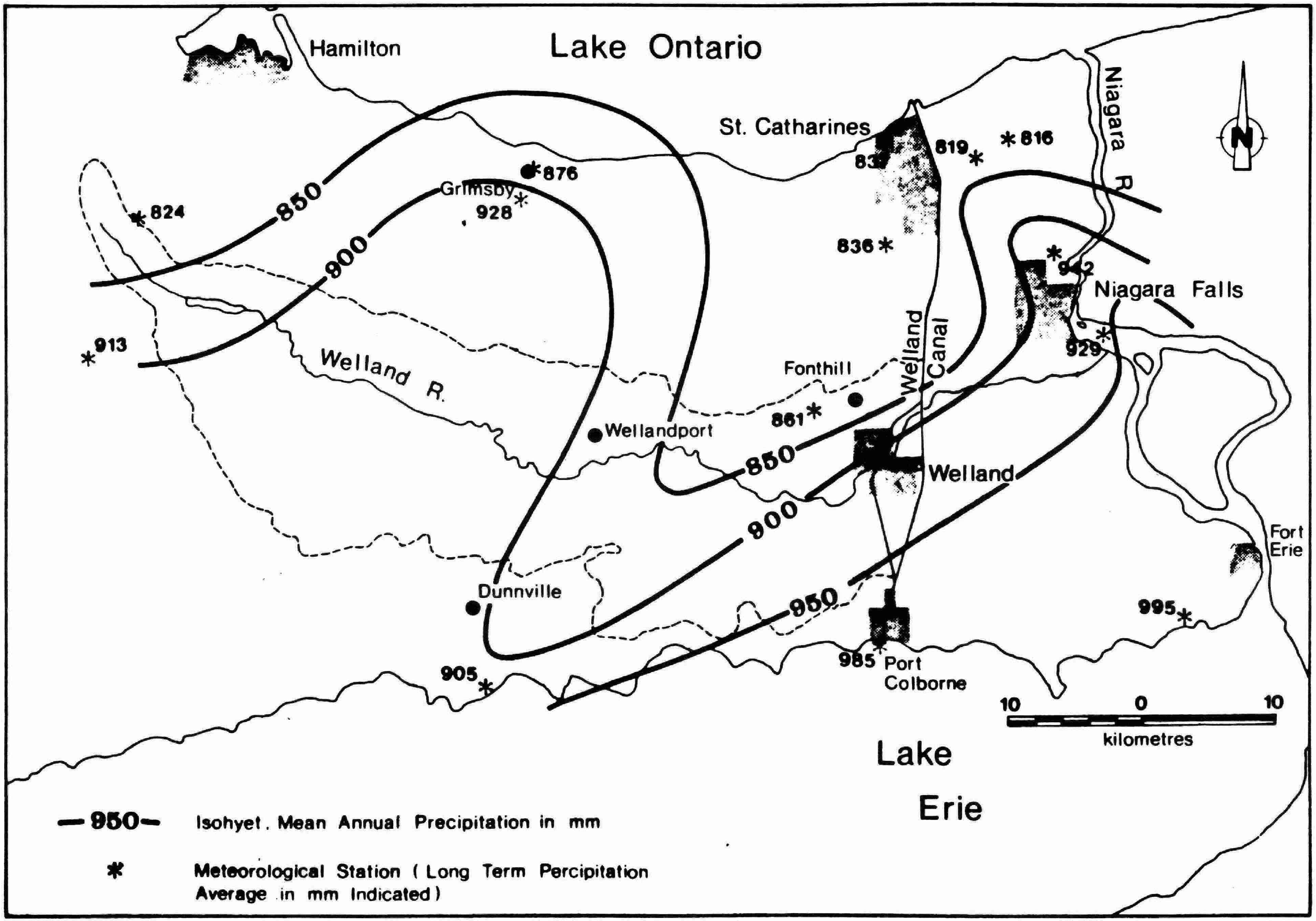


Figure 6 - Mean Annual Precipitation in the Niagara Area

3.0 GEOLOGY

3.1 BEDROCK GEOLOGY

The bedrock in the Niagara Peninsula is all of sedimentary origin and exhibits a slight (<1°) dip to the south. The dominant rock types are carbonates, shales, and sandstones. The slight southerly dip of the rocks exposes the various strata as east-west trending bands on the bedrock surface (Figures 7 and 8 in map pocket). These bands range in age from Ordovician (the oldest) at Lake Ontario to Devonian (the youngest) at Lake Erie (Figure 9). The presence of these rock units has been mapped by Hewitt (1972); Telford and Tarrant (1975a, 1975b); Telford, Liberty, and Feenstra (1976a; 1976b); and Freeman (1978).

Where a sequence of rocks contains a hard durable rock overlying a softer more easily eroded rock a bedrock cuesta is often formed. The two major bedrock features in the study area, the Niagara Escarpment and the Onondaga Escarpment are examples of this type of phenomenon.

The general composition of the bedrock units will be discussed below (from oldest to youngest, or north to south).

3.1.1 Ordovician

Ordovician rocks are exposed at the base of the Niagara Escarpment and northward to the Precambrian Shield north of Peterborough. Only the uppermost Ordovician unit, the Queenston Formation, is present as the uppermost bedrock unit in the Niagara Peninsula.

The Queenston Formation is composed of distinctive "brick red" shale with occasional thin hard carbonate beds. This formation is the oldest exposed in the Peninsula and outcrops at the base of the Niagara Escarpment. It is estimated to be more than 200 m in thickness.

3.1.2 Silurian

The Silurian rocks of the Niagara Peninsula occur south of the Niagara Escarpment. The basal Silurian formations are comprised of sandstones and shales and grade upwards into limestones and dolostones. The lower part of the Silurian rocks are exposed in the face of the Niagara Escarpment and progressively outcrop to the south towards Lake Erie.

PERIOD	GROUP	FORMATION	APPROXIMATE THICKNESS	LITHOLOGY
DEVONIAN		ONONDAGA	varies to 15 m	fossiliferous cherty limestone
		BOIS BLANC	3 to 4 m	fossiliferous cherty limestone
		ORISKANY	< 1 m	sandstone
SILURIAN		BERTIE	10 m	dolostone with shale
		SALINA	90 m	dolostone with shale
	ALBEMARLE	GUELPH	10 to 15 m	dolostone
		LOCKPORT	> 15 m	dolostone
	CLINTON	DECEW	4 m	dolostone
		ROCHESTER	14 m	shale with limestone
		IRONDEQUOIT	4 m	dolostone and limestone
		REYNALES	4 to 6 m	dolostone
		NEAHGA	1 to 2 m	shale
		THOROLD	2 to 3 m	sandstone and shale
	CATARACT	GRIMSBY	14 m	sandstone and shale
		POWER GLEN	12 m	shale
		WHIRLPOOL	6 m	sandstone
ORDOVICIAN	RICHMOND	QUEENSTON	> 200 m	shale

Figure 9 Bedrock Stratigraphy - Eastern Niagara Peninsula

Nine relatively thin formations of the Cataract and Clinton Groups overlie the Queenston Formation of Ordovician age. They total approximately 60 m in thickness and are exposed almost exclusively in the face of the Niagara Escarpment. The names and general lithologies of these formations are summarized on Figure 9 in the sequence in which they occur in the Niagara Escarpment (i.e., oldest at the base and youngest at the top).

The Lockport Formation overlies the Clinton Group rocks. It is composed of a hard resistant dolostone which forms the cap rock of the Niagara Escarpment. This formation totals more than 15 m in thickness.

The Guelph Formation overlies the Lockport and is also a dolostone. It is present as the uppermost bedrock unit over a 5 to 10 km wide band in the central part of the Niagara Peninsula (Figures 7 and 8 in map pocket). The Guelph Formation is estimated to be approximately 10 to 15 m thick.

The Salina Formation overlies the Guelph Formation and is the uppermost bedrock unit over a 10 to 12 km band in the south-central part of the Niagara Peninsula. The unit is composed of dolostone and shale and is notable in that it contains evaporites. The Salina Formation is approximately 90 m thick.

The Bertie Formation is composed of resistant dolostone with some shaley zones. It is approximately 10 m thick and forms the main erosion resistant unit of the Onondaga Escarpment.

3.1.3 Devonian

The Devonian rocks of the Niagara Peninsula occur south of the Onondaga Escarpment. They are generally well exposed at surface and are dominantly cherty fossiliferous limestones.

The Oriskany Formation, a thin (<1 m) fossiliferous sandstone, is occasionally found between the Bertie Formation of Silurian age and the overlying Bois Blanc Formation, but does not occur in the study area.

The Bois Blanc Formation is composed of fossiliferous cherty limestone with occasional shale and sandstone beds. The entire formation is approximately 3 to 4 m in thickness and is exposed in a 1 to 2 km thick band along the brow of the Onondaga Escarpment.

The Onondaga Formation is the youngest rock unit in the study area. It is composed of a sequence of fossiliferous cherty limestones which are exposed between the Onondaga Escarpment and the Lake Erie shore. Total thickness of the Onondaga Formation varies but generally exceeds 15 m.

3.2 STRUCTURAL GEOLOGY

The rocks of the Niagara area exhibit small scale structural features which may influence local hydrogeological conditions, although regional structure is uncomplicated.

The regional dip of the sedimentary bedrock units in the area has been measured at an average of 5.9 m/km (<1°) to the south-southeast (Huang et al., 1983). Local phenomena such as flexure of the rocks, stress release, and local reefal structures have been used to explain local variations from 0.9 to 36.0 m/km or up to 2° dip (ibid). The dip is generally too gradual to be observed visually.

There are no know major faults in the study area. Minor faults (less than 1 m displacement) have been noted by Kindle and Taylor (1913) and by White et al., (1973). Landsat imagery has suggested the existence of a linear "furrow" feature along the Niagara River but there is no evidence to demonstrate that this feature is related to faulting (Huang et al., 1983). Sanford et al., (1985) have suggested the presence of numerous small faults at depth in southwestern Ontario. These features have not been recognized at surface but the possibility exists that they may be present in the Niagara area.

Jointing and fracturing of the bedrock is observed whenever rock is exposed. Bedrock drilling (e.g., GLAL, 1985a; 1985b) also confirms the existence of fractures and joints in drift covered bedrock. Fracturing is common in all bedrock types but it is particularly well developed in the hard dolostones of the Guelph and Lockport Formations. Many wells obtain water from the upper few metres of fractured bedrock in these formations throughout the Niagara Peninsula.

Two general orientations of joint sets are common: one parallel to the brow of the Niagara Peninsula, and one at approximately 90° to it. Huang et al., (1983) have documented joint sets parallel to the Niagara Escarpment and parallel to the sides of the Niagara River Gorge and buried St. Davids Gorge. Williams et al., (1985) have also studied joints in the Niagara Peninsula and conclude that there is not consistent relationship between joint orientation, lithology, and geographic position. Observed spacing ranges from 0.1 m to 5 m and individual joints have been traced up to 300 m. The fact that these joint sets are parallel to major cuts in the rock suggests a stress-release origin for these features. The potential for solution enlargement of fractures and joints exists where water is able to move freely through carbonate bedrock. Similarly it is possible that evaporite minerals in the Salina Formation may also experience dissolution. Significant solution features may exist but they have not been generally identified or reported to occur in any abundance within the study area.

3.3 BEDROCK TOPOGRAPHY/DRIFT THICKNESS

Published bedrock topography mapping is available for the entire study area (Feenstra, 1981a; 1981b; 1981c; 1981d; 1981e; Flint and Lolcama, 1986) and this mapping has been compiled to produce the information presented on Figures 7 and 8 (in map pocket). The contour interval was reduced to 20 m on these maps so that it is possible to identify the significant trends at the 1:100 000 scale without excessive detail.

The bedrock topography is generally controlled by the difference in the durability of the rocks themselves coupled with their gentle southerly dip. The durable dolostones of the Lockport and Guelph Formations have resulted in the presence of the Niagara Escarpment trending east-west across the Niagara Peninsula. Similarly the Bertie and Bois Blanc Formations are associated with the Onondaga Escarpment on the south side of the Peninsula. Parallel east-west trending depressions are associated with the more erodible Queenston Formation shale (i.e. the Lake Ontario Basin) and the Salina Formation dolostones, shales and evaporites. These general relationships are depicted on Figures 7 and 8 (in map pocket).

Ancient fluvial erosion has superimposed its influence on the general pattern noted above. Various compilations of geologic and drilling data (Feenstra, 1981a; 1981b; 1981c; 1981d; 1981e; Flint and Lolcama, 1986) indicate the presence of buried channels which are predecessors of the modern Niagara River and its bedrock gorge. Although the exact position of many of these channels is subject to the interpretation of sparse data and interpreters do not always agree, the general location and significance of these channels is established, and is shown on Figure 10.

Published drift thickness mapping is also available for the study area (Vos, 1968; MOE, 1974b; Feenstra, 1982a; Feenstra et al., 1982). Figures 11 and 12 (in map pocket) depict the general drift thickness at a 1:100 000 scale. This information has been collated from the published drift thickness and bedrock topographic mapping noted above.

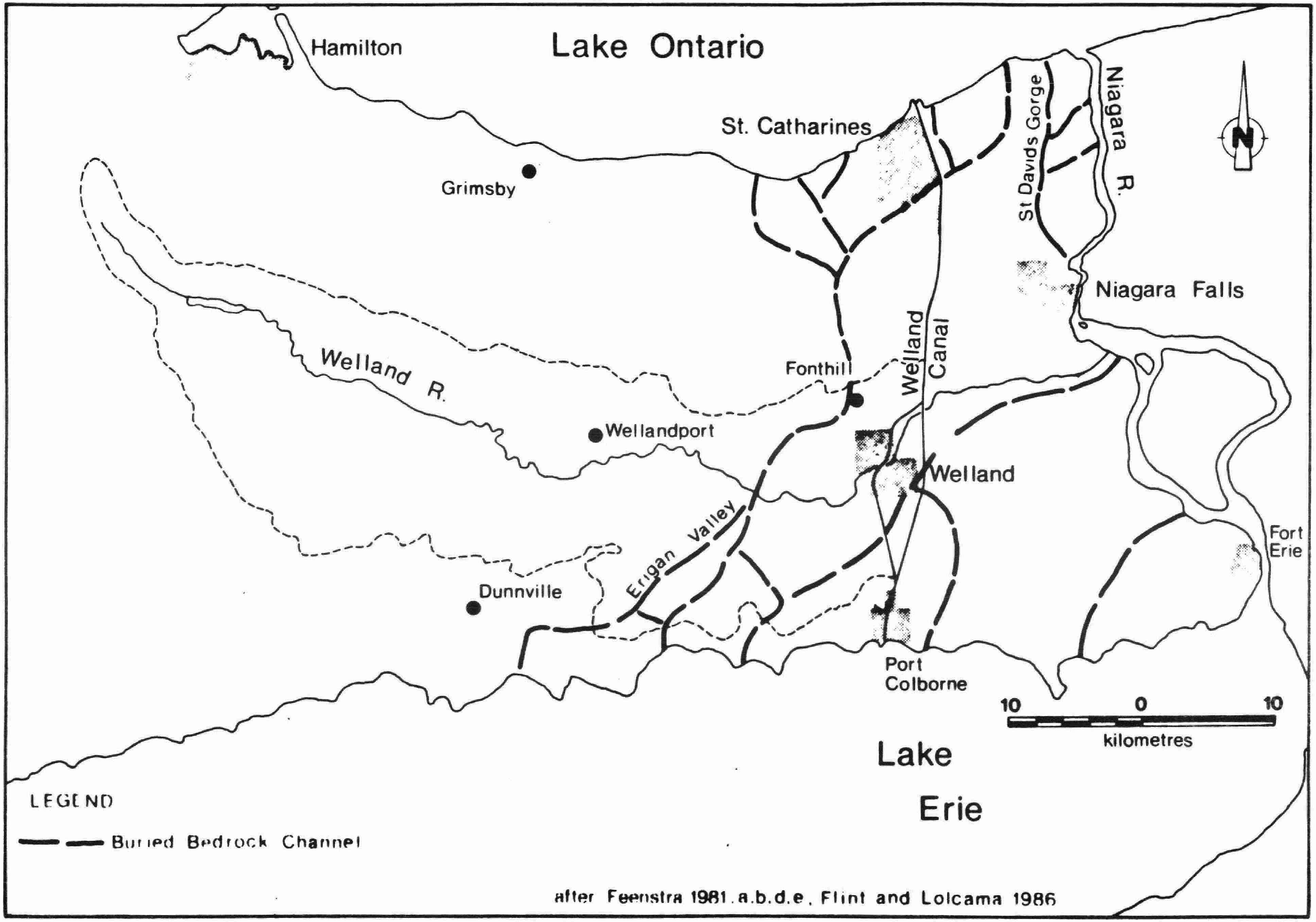
Areas of generally thin drift cover occur on top of the Niagara and Onondaga Escarpments. Areas of thick accumulations of glacial and proglacial sediments are found in the large trough associated with the presence of the Salina Formation, and the major buried drainageways such as the Erigan Channel and the St. Davids Gorge (Figures 10, and 11 and 12 in map pocket).

The Fonthill Kame is major geomorphic feature not directly related to bedrock. It is situated on the northern edge of the Welland River drainage basin. The Kame contains up to 60 m of unconsolidated materials and it directly overlies one of the deepest parts of the buried Erigan Valley (Figure 10) which contains an additional 40 m of material. These two features combine at Fonthill to yield a maximum drift thickness for the study area of more than 100 m (Figures 11 and 12 in map pocket).

3.4 QUATERNARY MATERIALS

3.4.1 General

The Quaternary geology of the Niagara Peninsula has been studied in detail by many authors. The presence of major exposures along the Welland Canal excavations and the geological, hydrogeological, and geotechnical studies associated with canal construction have provided a sound background for the interpretation of the geology of the area. Feenstra (1981a) culminated many years' field mapping in the Peninsula with publication of a detailed summary of the geology and history of the area. Other major publications



after Feenstra 1981 a,b,d,e, Flint and Lolcama 1986

Figure 10 - Bedrock Drainage Channels in the Niagara Area

addressing the area are cited by Feenstra and noted specifically as they are discussed in the following sections.

There are four major Quaternary geologic units found in virtually all parts of the Niagara Peninsula: the lower (Wentworth) till, the lower glaciolacustrine unit, the Halton Till, and the upper glaciolacustrine unit. These units are discussed in the following sections. Two other major units are located at the Fonthill Kame and at the buried St. Davids Gorge. These are also discussed separately. Proglacial lakes are addressed briefly followed by a description of post-glacial materials. The distribution of these materials in the study area is shown at a scale of 1:100 000 on Figures 13 and 14 (in map pocket).

3.4.2 Stratigraphy and History

The major Quaternary deposits, their lithology and morphology are summarized in Table 2. A brief account of the geological history of the area is presented here as an aid to understanding the spatial distribution of the materials and their hydrogeological significance.

The oldest known deposits in the study area are contained in the St. Davids Gorge. The sand, till, and other materials in the gorge have yielded dates of 23,000 years BP (before present) and their exact origin remains unknown.

A major ice advance covered the Niagara Peninsula approximately 22 000 to 14 000 years BP, during Late Wisconsinan time. This advance laid down the lower (Wentworth) till and associated sediments. As the ice retreated from the Peninsula into the Lake Ontario basin, a large proglacial lake formed. The lower glaciolacustrine unit was deposited in this lake, covering the Wentworth Till.

The ice readvanced out of the Lake Ontario basin approximately 13 000 years BP. It moved southwestward into the proglacial lake, covered most of the Niagara Peninsula, and deposited the Halton Till. The ice then retreated northward and a series of proglacial lakes were re-established in the area resulting in the upper glaciolacustrine unit and various small shoreline and related features (Figures 13 and 14 in map pocket).

Since drainage of the proglacial lakes approximately 11 000 to 12 000 years BP, sand dunes, flood plains, and bogs and swamps have been developed, but the landscape has changed little.

AGE	FORMATION / EVENT	LITHOLOGY	MORPHOLOGY
RECENT	Eolian	Sand	Coastal dunes
	Lake Erie, Ontario	Sand, gravel	Beach ridges
	Bog and swamp	Muck, peat	Filled depressions
	Alluvium	Gravel, sand. silt, clay, organic matter	Flood plains
	Eolian	Sand	Inland dunes
LATE WISCONSINAN	Upper glaciolacustrine	Clay, silt, some sand, gravel	Lake plains, with associated beaches etc.
	Halton Till	Silt-clay matrix	Ground and end moraine extensively buried
	Lower glaciolacustrine	Clay, silt, sand	Buried lake plain
	Lower till (Wentworth)	Stony sandy silt till	Buried ground moraine
EARLY / MIDDLE WISCONSINAN	Fluviatile-lacustrine	Fossiliferous sand (silt, clay)	Buried (St. Davids Gorge fill)
	Glacial?	Gravel, sand (till?)	Buried (St. Davids Gorge fill)

Table 2

Summary of Quaternary Geology in the Niagara area (After Feenstra, 1981a)

3.4.3 Lower Till Complex

Feenstra (1974; 1975; 1981a; 1984) has mapped a stony silty to sandy till overlying bedrock at many locations in the Niagara Peninsula. Barnett (1975) has concluded that this till sheet is equivalent to the Wentworth Till of the Hamilton area.

The lower or Wentworth Till exists as a continuous or nearly continuous till sheet. It has been observed along Lakes Ontario and Erie, along the brow of the Niagara Escarpment, in the Welland Canal excavations, and can be inferred from water wells in the heavily drift covered areas. Recent stratigraphic drilling near Niagara Falls (GLAL, 1985a; 1985b) and near Wellandport (GLAL, 1985c; 1985d) has examined this unit. It is a very dense silt to sandy silt till which contains occasional sand inclusions and locally very high proportions of gravel derived from local bedrock. It is commonly 2 to 4 m thick but may range locally to 10 m or more. Well drillers often note this unit as "hardpan". Where the till is thin and/or heavily charged with local bedrock fragments, it may not be recognized as a separate unit in drilling records. Water wells occasionally terminate in the lower till, particularly in the area north and west of Dunnville in the Caledonia Drumlin Field where till thickness are locally greater.

A sporadic areal distribution of basal granular materials has also been reported as water bearing by well drillers. However, the relationship of this material to the lower till is not clear and requires further investigation. It is likely glaciolacustrine in origin and only remnants of the original deposit remain.

3.4.4 Halton Till and Glaciolacustrine Units:

Three geologic units of silt-clay have been identified in the Niagara area (Owen, 1969; 1972; Feenstra, 1981a). These three units are the lower glaciolacustrine unit, the Halton Till, and the upper glaciolacustrine unit. The units are the result of glaciolacustrine deposition in a proglacial lake which was interrupted by a relatively weak glacial advance into the lake. The units show geological and geotechnical differences but their hydrogeological character is similar and they are addressed here as one unit.

The materials range in composition from clayey silt to silty clay and are generally very consistent in texture. Overall thickness range from zero near bedrock outcrops to more than 40 m in the area of the Salina Formation bedrock depression (Figures 7 and 8 in map pocket) and several of the deeper bedrock valleys (Figure 10). Water well drilling records suggest a very high degree of uniformity in these materials overall, although minor local textural variation has been identified in several areas where moraines or related features are present (Feenstra, 1981a; GLAL, 1986a).

Several moraines were formed during the advance and retreat of the ice which deposited the Halton Till. The positions of these features is of some hydrogeologic significance in that the Halton Till appears to thicken in places along the moraines, and may be associated with sand inclusions. Subsurface occurrences of sand are known adjacent to the Fonthill Kame (GLAL, 1984) and on the Niagara Falls Moraine (Feenstra, 1981a). The moraines are discontinuous and both the thickening of the Halton Till and the occurrence of buried sand are local conditions. The position of moraine features and the overall inferred ice-marginal positions are presented on Figure 15.

3.4.5 Fonthill Kame

The Fonthill Kame is a large and unusual glacial landform situated on the northern edge of the Welland River drainage basin. The feature is composed of approximately 60 m of sand and gravel, silt, and till, and is a major regional source of aggregates.

The formation of the feature is not fully understood but it is believed to have formed at the edge of the ice sheet which deposited the Halton Till during the formation of the Fort Erie and Niagara Falls Moraines. The Kame formed at the edge of the same lake (Lake Warren) which deposited the upper glaciolacustrine unit. Some intermixing of the silt-clays and the sands is known to exist in the subsurface on the edge of the Kame and it may be more accurately described as a "kame-delta complex". A veneer of glaciolacustrine sand and gravel cover the feature in the study area (Figure 14 in map pocket).

3.4.6 St. Davids Gorge

The buried St. Davids Gorge is an abandoned channel similar to the present Niagara River. The channel was infilled with a similar variety of gravels, sands, tills, silts, and clays which date to at least Middle Wisconsinan times (23 000 years BP).

These sediments have been investigated for their academic importance, extracted as a source of sand and gravel, and were used as a source of ground water for the nearby town of St. Davids. Hobson and Terasmae (1969) have investigated the feature. Feenstra (1981a, Figure 7) has compiled a variety of borehole, seismic, and exposure information on the Gorge and its contents.

3.4.7 Proglacial Lakes

The presence of a sequence of proglacial lakes in the study area has been recognized as part of a series of lake stages in the Erie and Ontario basins (Feenstra 1981a; Calkin and Feenstra, 1985; Muller and Prest, 1985). These lake stages are the result of dropping lake levels responding to the northward retreat of the glacial ice. The lakes are responsible for many of the smaller scale features noted on Figures 13 and 14 (in map pocket).

The upper glaciolacustrine unit and the Fonthill Kame were deposited in Lake Warren. This lake eroded several beach shorebluffs and accompanying terraces on the top of the Fonthill Kame. Small sand and gravel deposits mark the former beaches and bars in Lakes Wayne, Grassmere, Lundy, Early Algonquin, Dana, and Dunnville. These features are scattered throughout the Welland area and are commonly found on moraines. Lake Dana deposited a particularly large area of surficial sand and gravel in the St. Davids Gorge - Niagara Falls area. The ancestral Grand River entered Lake Dunnville at Dunnville - the resulting delta provided a sand source for the field of sand dunes located there. Lake Iroquois was the last of these lake stages in the study area. It left a well formed shorebluff with associated beach and bar, sand and gravels at the base of the Niagara Escarpment. The flat plain north of the Escarpment is the former lake bottom of Lake Iroquois and is composed of eroded till locally overlain by lacustrine sands, silts, and clays.

3.4.8 Postglacial Materials

Postglacial geologic phenomena are limited in the study area. River and creek erosion and deposition has resulted in the development of significant floodplains, particularly along the Welland River. The very low surface relief, coupled with the presence of the low permeability silts and clays of the Haldimand Clay Plain, have encouraged the growth of several large bogs. The Wainfleet Marsh, the Humberstone Marsh and marshes at Port Colborne and Crystal Beach collectively cover many square kilometres of land. Modern sand dunes have developed along the Lake Erie shoreline, particularly in the Port Colborne - Point Abino area (Figure 13 in map pocket).

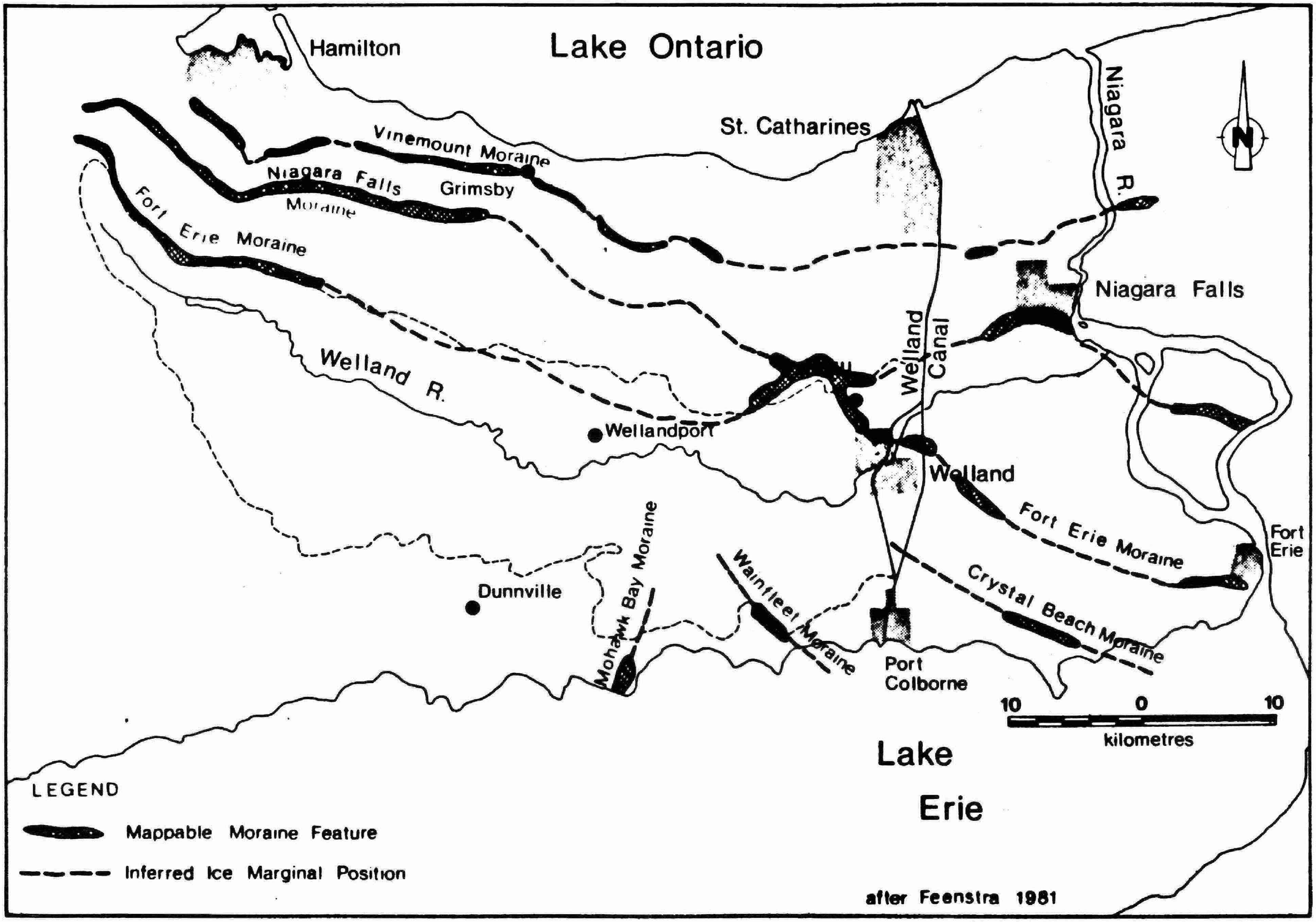


Figure 15 - Moraines and Ice - Marginal Positions in the Niagara Area

The Niagara Peninsula contains many areas of fill as a result of major construction/ excavation projects. These include large areas of land adjacent to the Welland Canal that have been covered by materials (mainly silt and clay) excavated during the construction of the Canal and related structures. Large areas of excavated rock fill are present in the Niagara Falls area. These materials were placed during excavations for the Queenston-Chippawa Power Canal, the aquaducts, and the reservoir facilities associated with the Sir Adam Beck Generating Stations. The large areas of fill are shown on Figures 13 and 14 (in map pocket).

4.0 HYDROGEOLOGY

4.1 HYDROGEOLOGIC UNITS

Hydrostratigraphic units are sequences of geologic materials that have similar hydrogeologic properties. The generalized hydrostratigraphy of the study area is presented in Table 3.

The hydrostratigraphic units are classified according to their ability to transmit water. In particular, an aquifer is defined as a water bearing horizon that will transmit significant amounts of water to a well.

Those horizons that will not transmit appreciable quantities of water are termed aquitards. Formations through which virtually no water moves are termed aquicludes.

The amount of water available to a well is dependant on the hydraulic conductivity (permeability) and porosity of the materials open to the well bore. The hydraulic conductivities of the geologic units in the study area are listed in Table 4. These data were compiled from technical reports completed for the Ontario Ministry of the Environment, Environment Canada, Ontario Hydro, and Ontario Waste Management Corporation.

4.1.1 Overburden Aquifer

The overburden aquifer is generally restricted to near-surface granular deposits found at Fonthill, St. Davids, Niagara Falls, and east of Welland. No other significant areas of overburden deposits are widely used to provide water for domestic or other purposes.

The results of three tests on the sands and gravels in the Fonthill and St. Davids areas indicated consistent values of hydraulic conductivities with those reported for similar materials in the literature, on the order of 10^{-4} m/s (Table 4).

4.1.2 Overburden Aquitard

A review of the data presented in Table 4 indicates that the finer-grained overburden materials of the upper glaciolacustrine unit are aquitards with reported hydraulic conductivities less than 10^{-7} m/s. Where these materials are weathered, they contain

HYDROSTRATIGRAPHIC UNIT	GEOLOGIC UNITS
overburden aquifer	post glacial deposits St. Davids Gorge deposits Fonthill Kame Complex
overburden aquitard	upper glaciolacustrine Halton Till lower glaciolacustrine lower till complex
bedrock aquifer	basal granular deposits weathered bedrock
bedrock aquitard	unweathered bedrock

Table 3 Hydrostratigraphy of the Niagara Area Study

GEOLOGIC UNIT	HYDRAULIC CONDUCTIVITY RANGE *** (m/s)	NUMBER OF TESTS **	HYDRO-STRATIGRAPHIC CLASSIFICATION	REMARKS
NEAR SURFACE GRANULAR				
GRAVEL	1E-05	1	Overburden Aquifer	Fonthill
SAND	2E-05 - 2E-04	2		St. Davids George
UPPER GLACIOLACUSTRINE				
SILT	2E-09 - 3E-06	11	Overburden Aquitard	Higher values from sandier materials
SILT CLAY	2E-10 - 7E-07	10		
CLAY (WEATHERED)	2E-09 - 7E-07	37		Includes fractured clay
CLAY (UNWEATHERED)	5E-11 - 1E-09	57		
SILT TILL (HALTON)	1E-10 - 7E-05	40		Higher values from sandy/granular (Wentworth) till
SHALLOW BEDROCK				
ONONDAGA FORMATION			Bedrock Aquifer	No data
BOIS BLANC FORMATION	6E-07 - 1E-06 *	3		
BERTIE FORMATION	9E-08 - 2E-06 *	18		
SALINA FORMATION	1E-05 - 6E-04 *	2		
GUELPH FORMATION	3E-11 - 1E-05 *	45		
LOCKPORT FORMATION	5E-09 - 4E-03 *	52		
DEEP BEDROCK				
CLINTON GROUP	4E-11 - 5E-06	88	Bedrock Aquitard	Higher values from Irondequoit and Decew Formations
CATARACT GROUP	7E-12 - 2E-07	31		Higher values from Whirlpool Formation
QUEENSTON FORMATION	6E-12 - 1E-08	31		Does not include weathered Queenston Formation north of the Niagara Escarpment

NOTES : * weathered bedrock surface is generally more permeable (higher value) than the underlying bedrock

** slug tests, constant head tests, and pump tests.

*** data obtained from technical reports prepared for Ontario Ministry of the Environment, Ontario Waste Mangement Corporation, Environment Canada, and Ontario Hydro.

Table 4 - Hydraulic Conductivities of the Geologic Units in the Niagara Area

numerous interconnected fractures that can transmit very small amounts of ground water. Testing of the unweathered materials indicates hydraulic conductivities of less than 10^{-9} m/s for these formations (Table 4).

The extent of weathering and frequency of fractures decrease gradually with depth according to studies conducted on silt and clay materials by several investigators (Grisak et al., 1976; Goodall and Quigley, 1977; Desaulniers et al., 1981; Desaulniers, 1982). The hydraulically active part of the weathered zone is estimated to be only 2 to 3 m deep for the most part with a maximum of about 5 m (GLAL, 1986a).

Below the weathered zone, ground water movement is dominated by the matrix or intergranular porosity of the materials. Laboratory testing by GLAL (1986a) yielded matrix porosities ranging from 0.38 to 0.48. Desaulniers (1980) indicated a range of porosities from 0.34 to 0.70 for silt and clays in the Wainfleet area which is east of Dunnville in the southern part of the Niagara study area. Fracture porosities of silt and clay (in the weathered zone) have been estimated to be in the order of 1×10^{-4} by Grisak et al., (1976) and Desaulniers (1982). Consequently, the total or bulk porosity of the materials tends to be the same as the matrix porosity.

GLAL (1986a) reports porosities to range from 0.17 to 0.24 for sandy silt till. The range in hydraulic conductivities is reported to be from 1×10^{-10} to 7×10^{-5} m/s (Table 4). The higher permeabilities are probably due to sand and gravel layers reported to be present in the till at some locations.

Hydraulic conductivity information is not available for the lower glaciolacustrine unit; however its characteristics are anticipated to be similar to the unweathered upper glaciolacustrine unit with reported values of less than 1×10^{-9} m/s.

4.1.3 Bedrock Aquifer

Hydraulic conductivities in the predominantly carbonate (limestone/dolostone) and shale (north of the Niagara Escarpment) bedrock formations in the study area are highly variable. Water is transmitted in these rocks, primarily via bedding planes and secondary openings such as joints and fractures, and also solution cavities in carbonate rocks.

Higher hydraulic conductivities are reported for the Lockport, Salina, and Guelph Formations than the shaley units such as the Queenston Formation and the Rochester, Neahga, Grimsby, and Power Glen Formations of the Clinton and Cataract Groups (Table 4). The higher hydraulic conductivities are likely due to better interconnection of voids in the more competent carbonate formations. The bulk porosity of the Silurian carbonates ranges up to 0.10 (personal communication R.A. Trevail, 1987).

The information used to prepare Table 4 indicates that for a given rock type, the uppermost part of the bedrock has a higher hydraulic conductivity than the same formation at depth. This is attributed to weathering of the bedrock surface and is also evidenced by water well record data on file with the Ontario Ministry of the Environment (MOE, 1978b; 1981d; 1982c). These data indicate that most bedrock water wells obtain their water from the uppermost part of the bedrock.

Significant quantities of water are reported for some wells completed in the shaley Queenston Formation north of the Niagara Escarpment. However, no quantitative results for hydraulic conductivity are available. These wells are presumed to be completed either in locally highly weathered/fractured zones at the bedrock surface of the Queenston Formation, or in areas where overlying basal granular deposits are in hydraulic connection with the bedrock.

4.1.4 Bedrock Aquitard

Review of the data presented in Table 4 indicates significantly lower hydraulic conductivities for the underlying bedrock formations. In particular, the bedrock data in Table 4 were compiled for formations subcropping south of the Niagara Escarpment. The hydraulic conductivities of the deeper bedrock formations comprised of the Clinton and Cataract Groups, and the Queenston Formation are lower by about one to three orders of magnitude than the overlying Lockport to Onondaga Formations.

The formations overlying the Clinton and Cataract Groups form the bedrock surface south of the Niagara Escarpment, whereas the Clinton and Cataract Groups subcrop only in the face of the Escarpment. Consequently, secondary permeabilities due to widespread weathering of the bedrock surface would only have been developed to the same degree in the Clinton and Cataract Groups near the Escarpment face.

The data used to compile Table 4 also indicate that the more competent units, such as the carbonates of the Irondequoit and Decew Formations and the sandstone of the Whirlpool Formation, have hydraulic conductivities ranging from 1 x 10^{-9} to 5 x 10^{-6} m/s and form the upper permeable limits of the Clinton and Cataract Groups.

Hydraulic conductivities in the shaley formations, comprised of the Rochester, Neahga, and Power Glen, generally form the lower limits, ranging from 7 x 10^{-12} to 1 x 10^{-8} m/s.

The shaley Queenston Formation is highly variable in hydraulic conductivity ranging from 6 x 10^{-12} to 1 x 10^{-8} m/s. The values reported in Table 4 are for deep boreholes drilled near the Niagara River. With the exception of a hydraulic conductivity of 1 x 10^{-8} m/s reported for a 2.8 m interval near the top of the Queenston Formation in one of the boreholes, the remaining values were reported to be less than 1 x 10^{-10} m/s. As indicated in the preceeding section on bedrock aquifers, it is possible to obtain a water supply from the weathered bedrock surface of the Queenston Formation. However, the generally low hydraulic conductivities and significant thickness of greater than 200 m potentially classifies this formation as an aquiclude or barrier to deep ground water flow.

4.2 WELL YIELDS

Water well yields are dependant on the hydrogeologic properties of the materials in which the wells are completed. Pumping tests are a measure of the well yield. The theoretical yields of water wells in the study area were computed from pumping test data reported in the water well records on file with the Ontario Ministry of the Environment (MOE, 1987b; 1981d; 1982c). The specific capacity of the well (Q/s) multiplied by its available drawdown (s') were used to calculate the theoretical yield where:

Q = pumping rate reported from pump test
s = drawdown reported at end of pump test
s' = available drawdown calculated from reported static water level

For presentation purposes and consistent with previous Ontario Ministry of the Environment publications, the calculated yield was reduced by one half. A safety factor of two was used because the short term pumping data reported in the water well records may not represent long term yields. The general Ministry practice has been to use a factor of two for rock and a factor of three for overburden divided into the theoretical yield to obtain a more realistic or conservative estimate of yield as follows. The calculated yield used in this report is shown below:

$$\text{YIELD} = \frac{Q}{s} \times \frac{s'}{2}$$

The distribution of the high yielding water wells (greater than 2 L/s) is shown on Figures 16 and 17 (in map pocket).

The water well data indicate that the majority of these wells are completed in the bedrock aquifer (Table 3). Areas of high bedrock yields are reported throughout the study area.

The high yielding overburden wells shown in Figures 16 and 17 (in map pocket) are generally completed in granular materials overlying, and hydraulically connected to the bedrock. However, these basal granular materials are restricted in their occurrence. High yielding wells completed in the overburden materials are found in the following areas:

- in the basal sands of the headwaters area of the Welland River basin from Mount Hope to Caistor Centre
- in the basal sands of the south-central part of the Welland River basin north of Dunnville
- in the kame deposits of the Fonthill area northwest of Welland
- in the valley fill deposits in the vicinity of Niagara Falls and St. Davids
- in the basal sands of the Lake Ontario plain west of Virgil.

4.3 GROUND WATER LEVELS

The water table is the upper ground water surface and fluctuates in response to water infiltrating from the ground surface through the unsaturated zone. Changes in ground water levels can be measured in water wells or similar installations. The change in ground water levels is shown in the hydrographs of four observation installations (wells) in the bedrock aquifer and overburden aquitard as shown in Figures 18 and 19 (Ostry, 1971; MOE, 1977; 1978c; 1978d; 1979b; 1979e; 1981c; 1982b; GLAL, 1986b). The location of these installations is shown on Figures 3 and 4 (in map pocket).

Unfortunately, continuous records of water levels are not available for the study area. Nevertheless, the partial records shown in Figures 18 and 19 indicate a cyclical pattern. In particular, a general similarity of annual peaks in the spring months corresponds to maximum ground water recharge. Annual lows in the late summer/fall correspond to maximum depletion of infiltrating water by vegetation and evaporation. Deviations to this pattern do occur. For example, when precipitation exceeds evaporation during the growing season, or conversely when infiltration does not occur because of frozen ground conditions or lack of precipitation.

Figure 19 shows water level hydrographs for three monitors at different depths in the overburden aquitard. Lower water levels are observed with greater depths of the monitors indicating ground water recharge (i.e. downward ground water movement). The reverse conditions, higher water levels with deeper monitor depth, indicates ground water discharge (i.e. upward ground water movement). This latter condition is commonly observed in valleys as evidenced by flowing conditions (above the valley floor) from monitors or wells installed at depth.

Flowing wells have been reported in the St. Davids area, along the Onondaga Escarpment near Lake Erie, and in the Pelham area northwest of Fonthill (MOE, 1981b).

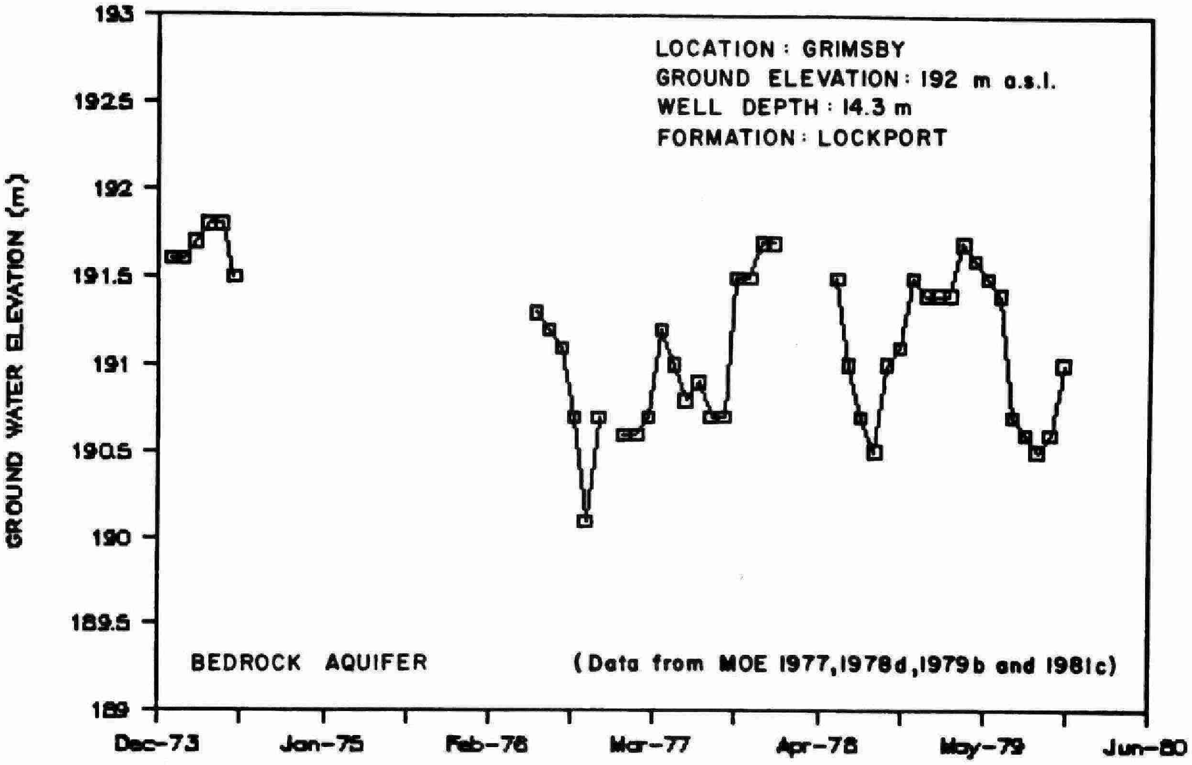
Figure 19 also illustrates a common occurrence of smaller water level fluctuations as the depth of the monitor below the water table increases. The water level fluctuations become less pronounced because of the dampening effects of smaller pressure differentials at greater depths below the water table.

4.4 GROUND WATER MOVEMENT

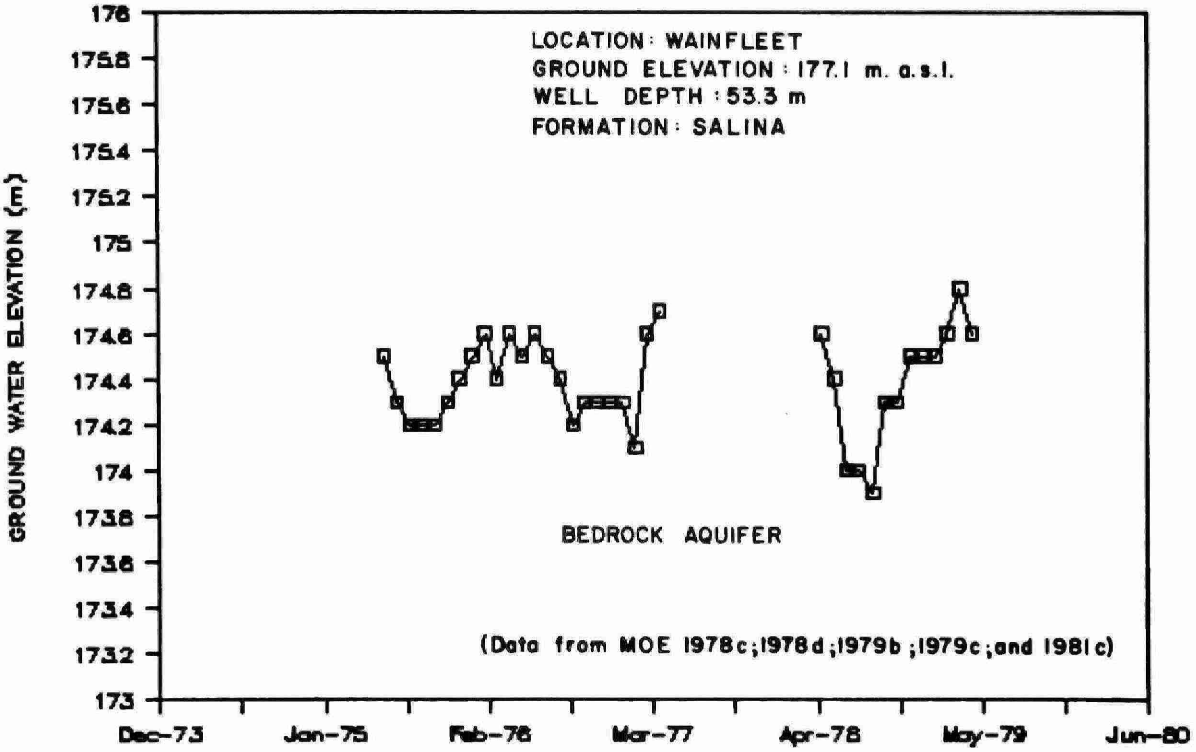
The level to which water rises in a well is a measure of the ground water or hydraulic head at the point where the water was found. The hydraulic head controls ground water movement; with movement of water by gravity towards areas of lower potential or

Figure 18 - Observation Well Hydrographs

Grimsby
18a - HYDROGRAPH, WELL NO. 399



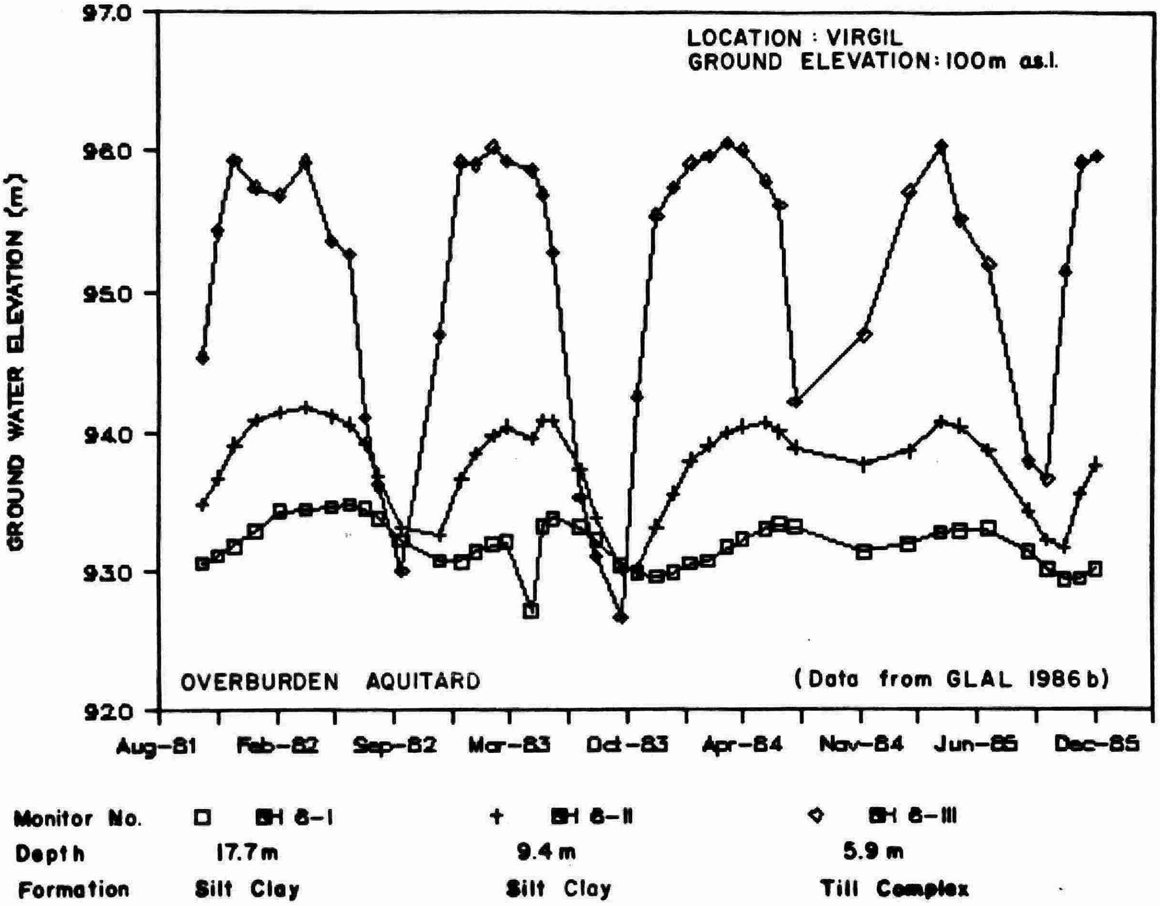
Wainfleet
18b HYDROGRAPH, WELL NO. 228



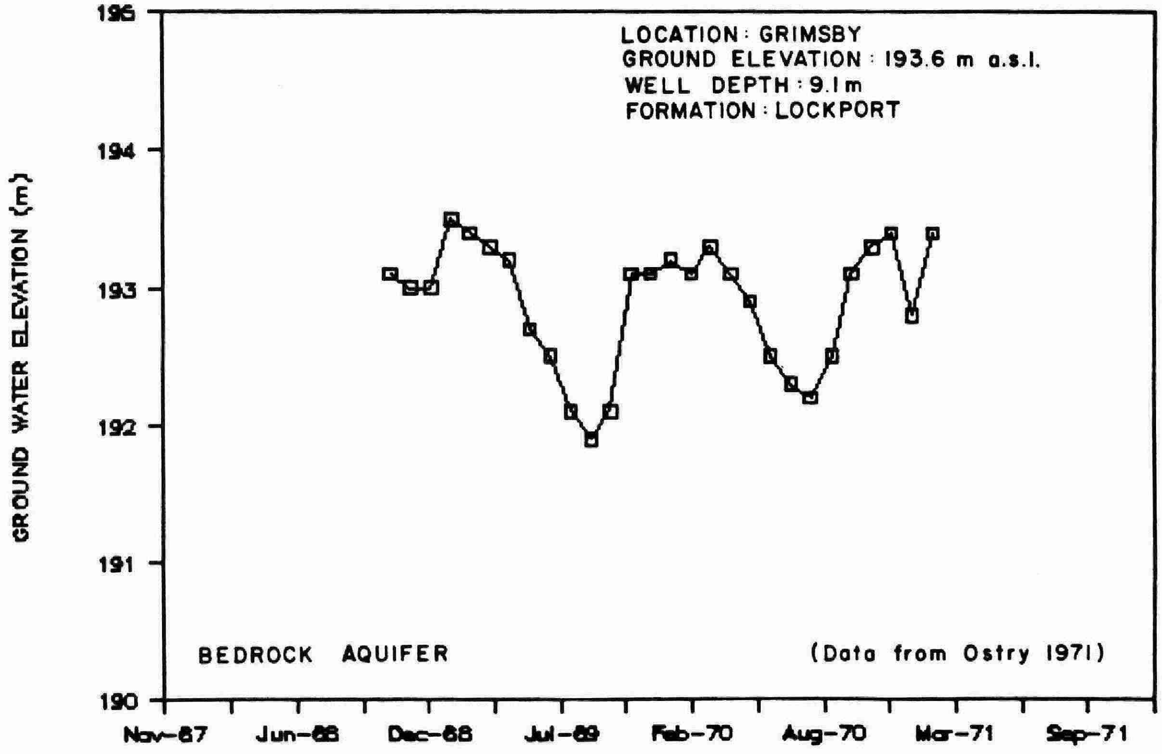
Data from MOE, 1977; 1978c; 1978d; 1979a; and 1979b.

Figure 19 - Observation Well Hydrographs

19a - HYDROGRAPHS, BOREHOLE #6 (Virgil)



19b - HYDROGRAPH, WELL NO. FM27 (Grimsby)



hydaulic head as defined by Hubbert (1953). Under natural conditions, ground water flows from areas of high to low potential; however, when a well is pumped it changes the hydraulic potential by lowering the water level such that water will flow to the well from the surrounding water bearing zone.

Potentiometric maps were prepared for the bedrock (Figures 20 and 21 in map pocket) and the overburden (Figures 22 and 23 in map pocket) based on water levels reported in the water well records on file with the Ontario Ministry of the Environment (MOE 1987b; 1981d; 1982c). The potentiometric surfaces for the overburden and bedrock are similar. The similarity between the maps (Figure 20 to 23 inclusive) is attributed to hydraulic continuity or connection at the bedrock surface. In particular, the overburden data were compiled from water wells completed in basal overburden materials overlying the bedrock.

The potentiometric surface maps indicate the following:

- ground water divides generally coincide with the surface water divides
- ground water movement is towards ground water discharge areas which usually are topographically low areas (e.g., in the shallow ground water system, regional ground water discharge is to Lake Ontario in the north; Lake Erie in the south; and the Welland and Niagara Rivers in the central and eastern parts of the study area, respectively).

Detailed studies (GLAL, 1986a) indicate that the water table fluctuates over the weathered/fractured upper two to three metres of the glaciolacustrine silts and clays comprising the overburden aquitard (Table 3). The studies indicate that flow in this shallow zone responds to daily climatic changes such that, during precipitation, the open fractures from weathering will quickly fill with water. The bulk of the discharge will then occur locally in swales that carry intermittent surface water to permanent streams. The remainder will go to depth to recharge the ground water system. During periods of no precipitation, the water table will fall to, or just below the swales promoting deep ground water flow from the water table through the overburden aquitard into the bedrock aquifer.

Ground water water movement in the bedrock aquifer can be inferred from areas of high to low potential shown on Figures 20 to 23 inclusive (in map pocket).

Below the bedrock aquifer, hydraulic head information within the bedrock aquitard is limited. Deep boreholes, drilled to establish a geological and hydrogeological data base for hydroelectic and research purposes in the vicinity of the Niagara River on Navy Island and near St. Davids, indicate (personal communication K. Novakowski, 1987) very high hydraulic heads at the bottom of the Lockport Formation which is about 50 m below the ground surface. The Lockport Formation in this locale is below the zone of vertical connection where significant lateral ground water movement occurs at the bottom of the shallow ground water system. The hydraulic heads below the Lockport Formation are in the order of tens of metres above the ground surface and would act as a barrier to vertical ground water movement from the shallow ground water system. Heystee et al., 1985 also indicated that large vertical gradients occur at depth across the less permeable horizons such as the Rochester Formation indicating a strong potential for downward movement of ground water below the Clinton Group. Downward gradients below the shallow ground water system have also been reported by Ostry (1971) in this same rock sequence near the Niagara Escarpment north of the study area at Grimsby.

The influence of the Niagara Escarpment on the deeper hydraulic heads in the areas noted above is not clear. Both areas discussed above are within a few kilometres of the Escarpment and may be influenced by dewatering effects close to the scarp face. Further studies are required to determine the hydraulic head distribution below the bedrock aquifer in the rest of the study area.

4.5 GROUND WATER CHEMISTRY

No field sampling or chemical analysis of ground water was undertaken for this study. Existing analyses of ground waters (background quality) were obtained from a variety of sources (OWRC, 1962; SLSA, 1968; MOE, 1974; GLAL, 1978; MOE, 1979; Zenon Environmental Inc., 1985; GLAL, 1986a; Golder Associates, 1986). The chemistry results from these analyses have been tabulated in Table 5. All of the analyses are considered to represent background conditions and any suspect analyses were removed from the data base. Most of the analyses are for water samples obtained from the bedrock aquifer. Only four analyses representing background conditions were available for the overburden aquifer which has limited distribution in the vicinity of Niagara Falls, St. Davids, and Fonthill.

Specific electrical conductance is a measure of the ion concentration of water and can be used as a qualitative measure of overall water quality. Water quality criteria have not been established for this parameter for drinking water. However, criteria are available for irrigation waters (McKee and Wolf, 1963), as shown below in Table 6. These criteria were used as an indication of water quality in the overburden aquitard and bedrock aquifer, where chemistry data were generally available.

4.5.1 Overburden Aquitard

Studies (Desaulniers, 1980; Desaulniers et al., 1981; Heystee, 1982; and GLAL, 1986a) indicate that shallow ground waters in the upper part of the fine-grained overburden (overburden aquitard) are characterized by very high concentrations of major ions. The specific electrical conductance in shallow monitors to a depth of 9 m is reported (GLAL, 1986a) to range from 3,400 to 9,680 uS. Below 9 m, concentrations of the chemical constituents are reported to decline rapidly reaching levels approximately 5 to 15 times lower at a depth of 25 m. The high ionic concentrations in the shallow overburden are attributed to the solution of readily available constituents in the highly weathered and/or fractured portion of the near-surface silt and clay materials by downward percolating water (GLAL, 1986a). The changes in the major ion concentrations were interpreted to be the result of slow (mm/a) downward movement and diffusion of dissolved constituents from the shallow (poor quality) overburden aquitard mixing with the better quality, deep overburden (bedrock aquifer) ground water (GLAL, 1986a). The study further noted that upward diffusion of constituents could also occur if poorer quality water were present in lower aquifers.

4.5.2 Bedrock Aquifer

Figure 24 shows the specific electrical conductance of ground water across the study area. The values range from 643 to 4,950 uS. In general, the distribution shown on Figure 24 suggests that the specific electrical conductance of ground waters from overburden wells is slightly lower than water from bedrock wells. The majority of both the overburden and bedrock well waters fall into the Class III (unsuitable) designation for irrigation waters. Very few wells in the study area have waters in the Class I or Class II suitable designations (Table 6).

PARAMETER	MOE DRINKING WATER OBJECTIVES	WELL : 85-8-1 (1)	NF-2-1 (2)	NF-3-1 (2)	NF-4-1 (2)	26-50 (3)	26-257 (3)	26-759 (3)	26-787 (3)	26-811 (3)	26-40 (3)	26-65 (3)	26-218 (3)
		DEPTH : 36.49 to 39.47 m	12 - 18 m	13 - 18 m	13 - 18 m	14 - 46 m	14 - 46 m	14 - 46 m	14 - 46 m	14 - 46 m	18 - 45 m	18 - 45 m	18 - 45 m
		DATE : 21-Aug-86	Apr-85	Apr-85	Apr-85	18-July-72	06-June-72	17-July-72	15-Jan-73	09-June-72	15-June-72	16-June-72	06-June-72
pH	(((6.5 to 8.5)))	7.3	8	8.2	8.1	7.6	---	7.5	7.6	---	7.2	7.1	---
Elect. Conductance	--	2100	650	750	2800	4393	3780	3100	2950	2976	3889	3268	4800
TDS	((500))	2960	---	---	---	3900	3600	3050	2570	2720	3890	3230	4150
Alkalinity	(((500)))	62	71	270	390	36	33	66	30	180	212	28	45
Chloride	((250))	45.9	18	22	430	572	197	49	11	25	12	95	590
Sulphate	((500))	1540	400	240	730	1862	2100	1890	1985	1650	2323	2000	2000
Nitrate	(10)	---	---	---	---	0.2	0.01	0.1	0.05	1.4	<0.01	0.01	0.11
Fluoride	(2.4)	2.18	1.5	1	0.5	---	1.2	1.4	1	1	1.4	1.4	1.2
Hardness	(((500)))	---	---	---	---	2080	1920	1860	1720	1780	2500	1790	2090
Calcium		363	125	142	176	632	556	624	496	516	504	500	540
Magnesium		115	19.1	42	32	121	129	73	117	119	301	131	180
Sodium	*	146	11.7	17	240	304	300	110	186	96	145	225	391
Potassium		3	8	2	18.8	9.6	6.2	9	3.8	5.5	6.9	8	8.7
Boron	(5.0)	---	---	---	---	8	1.7	2	---	0.71	1.38	2.14	1.8
Phosphorus		---	---	---	---	---	---	---	---	---	---	---	---
Aluminum	(((0.1)))	---	0.14	0.16	24	---	---	---	---	---	---	---	---
Silicon		4.09	---	---	---	---	---	---	---	---	---	---	---
Strontium		9.41	0.81	0.84	1.4	---	---	---	---	---	---	---	---
Barium	(1.0)	---	0.03	0.02	0.07	---	---	---	---	---	---	---	---
Beryllium		---	<0.005	<0.005	<0.005	---	---	---	---	---	---	---	---
Molybdenum		---	0.03	0.08	0.03	---	---	---	---	---	---	---	---
Vanadium		---	0.01	0.01	0.01	---	---	---	---	---	---	---	---
Iron	((0.3))	---	---	---	---	5.2	0.65	0.85	0.65	1.9	4.5	6.4	0.75
Cyanide	(0.2)	---	0.01	0.01	0.01	---	---	---	---	---	---	---	---

NOTES: ((( ))) - MOE Drinking Water Objective - aesthetic limit
(( )) - MOE Drinking Water Objective - maximum desirable concentration
( ) - MOE Drinking Water Objective - maximum acceptable concentration
* - notification of Health Dept. with > 20 mg/L
- units in mg/L - conductance in uS - pH has no units - location are shown on Figure 24

(1) data from GLAL, 1986a
(2) data from Zenon, 1985
(3) data from MOE, 1974
(4) Data from Golder Associates, 1987

(5) Data from GLAL, 1978
(6) Data from SLSA, 1968
(7) Data from MOE, 1979
(8) Data from OWRC, 1962

Table 5 Chemical Analyses of Ground Water Samples in the Niagara Area

PARAMETER	MOE DRINKING WATER OBJECTIVES	WELL : 3531 (6)	110 (6)	3521 (6)	3502 (6)	3515 (6)	3532 (6)	50 (6)	169 (6)	3589 (6)	66-672 (7)	66-1234 (8	3507 (6)
		DEPTH : 36.6 m	37.8 m	--	--	25.9 m	27.4 m	32.9 m	9.4 m	4.9 m	14.6 m	14.0 m	25.6 m
		DATE : Nov-68	Nov-68	Nov-68	Nov-68	Nov-68	Nov-68	Nov-68	Nov-68	Nov-68	26-Nov-79	Apr-61	Nov-68
pH	(((6.5 to 8.5)))	--	--	--	--	--	--	--	--	--	7.5	7.8	--
Elect. Conductance	--	4950	643	2900	3080	3000	2750	3570	2130	975	660	350	2900
TDS	((500))	--	--	--	--	--	--	--	--	--	470	298	--
Alkalinity	(((500)))	--	--	--	--	--	--	--	--	--	233	142	--
Chloride	((250))	--	--	--	--	--	--	--	--	--	57	11	--
Sulphate	((500))	--	--	--	--	--	--	--	--	--	54	48	--
Nitrate	(10)	--	--	--	--	--	--	--	--	--	5.6	---	--
Fluoride	(2.4)	--	--	--	--	--	--	--	--	--	<0.1	---	--
Hardness	(((500)))	--	--	--	--	--	--	--	--	--	340	210	--
Calcium		--	--	--	--	--	--	--	--	--	83	---	--
Magnesium		--	--	--	--	--	--	--	--	--	32	---	--
Sodium	*	--	--	--	--	--	--	--	--	--	24	---	--
Potassium		--	--	--	--	--	--	--	--	--	1.4	---	--
Boron	(5.0)	--	--	--	--	--	--	--	--	--	---	---	--
Phosphorus		--	--	--	--	--	--	--	--	--	---	---	--
Aluminum	(((0.1)))	--	--	--	--	--	--	--	--	--	---	---	--
Silicon		--	--	--	--	--	--	--	--	--	---	---	--
Strontium		--	--	--	--	--	--	--	--	--	---	---	--
Barium	(1.0)	--	--	--	--	--	--	--	--	--	---	---	--
Beryllium		--	--	--	--	--	--	--	--	--	---	---	--
Molybdenum		--	--	--	--	--	--	--	--	--	---	---	--
Vanadium		--	--	--	--	--	--	--	--	--	---	---	--
Iron	((0.3))	--	--	--	--	--	--	--	--	--	<0.05	0.0	--
Cyanide	(0.2)	--	--	--	--	--	--	--	--	--	---	---	--

NOTES: ((( ))) - MOE Drinking Water Objective - aesthetic limit
(( )) - MOE Drinking Water Objective - maximum desirable concentration
( ) - MOE Drinking Water Objective - maximum acceptable concentration
* - notification of Health Dept. with > 20 mg/L
- units in mg/L - conductance in uS - pH has no units - location are shown on Figure 24

(1) data from GLAL, 1986a
(2) data from Zenon, 1985
(3) data from MOE, 1974
(4) Data from Golder Associates, 1987

(5) Data from GLAL, 1978
(6) Data from SLSA, 1968
(7) Data from MOE, 1979
(8) Data from OWRC, 1962

Table 5 (cont'd) Chemical Analyses of Ground Water Samples in the Niagara Area

PARAMETER	MOE DRINKING WATER OBJECTIVES	WELL : 26-227 (3)	26-258 (3)	26-763 (3)	26-768 (3)	26-788 (3)	26-1292 (3	D-1 (4)	FE-1-I (5)	3358 (6)	3519 (6)	116 (6)	3507 (6)
		DEPTH : 18 - 45 m	18 - 45 m	18 - 45 m	18 - 45 m	18 - 45 m	18 - 45 m	14.0 m	7.0 m	33.8 m	19.8 m	33.5	25.6 m
		DATE : 18-July-72	18-July-72	08-June-72	08-June-72	17-July-72	18-July-72	Jul-75	Mar-78	Nov-68	Nov-68	Nov-68	Nov-68
pH	(((6.5 to 8.5)))	7.8	7.6	---	---	7.3	7.3	7.3	--	--	--	--	--
Elect. Conductance	--	3308	3527	3888	2425	3828	3770	1600	1060	3000	3250	3850	2900
TDS	((500))	3350	3600	3340	2200	4150	3500	--	--	--	--	--	--
Alkalinity	(((500)))	70	36	189	64	218	74	312	--	--	--	--	--
Chloride	((250))	36	43	287	27	53	297	49	--	--	--	--	--
Sulphate	((500))	2079	2209	1800	1260	2400	1691	550	--	--	--	--	--
Nitrate	(10)	<0.01	0.01	<0.01	<0.01	0.04	<0.01	--	--	--	--	--	--
Fluoride	(2.4)	---	---	1.1	1.5	1.4	---	--	--	--	--	--	--
Hardness	(((500)))	1820	1920	1770	1310	2500	2100	805	--	--	--	--	--
Calcium		547	593	508	360	656	569	--	--	--	--	--	--
Magnesium		109	106	122	100	209	162	--	--	--	--	--	--
Sodium	*	209	235	318	118	139	217	14	--	--	--	--	--
Potassium		3.7	6.4	28	5.1	4.5	6.3	2.6	--	--	--	--	--
Boron	(5.0)	1.1	1.5	3.6	0.38	0.8	1.3	--	--	--	--	--	--
Phosphorus		---	---	---	---	---	---	0.02	--	--	--	--	--
Aluminum	(((0.1)))	---	---	---	---	---	---	---	--	--	--	--	--
Silicon		---	---	---	---	---	---	---	--	--	--	--	--
Strontium		---	---	---	---	---	---	---	--	--	--	--	--
Barium	(1.0)	---	---	---	---	---	---	---	--	--	--	--	--
Beryllium		---	---	---	---	---	---	---	--	--	--	--	--
Molybdenum		---	---	---	---	---	---	---	--	--	--	--	--
Vanadium		---	---	---	---	---	---	---	--	--	--	--	--
Iron	((0.3))	4.8	0.5	2.9	0.55	0.45	6.1	---	--	--	--	--	--
Cyanide	(0.2)	---	---	---	---	---	---	---	--	--	--	--	--

NOTES: ((( ))) - MOE Drinking Water Objective - aesthetic limit
(( )) - MOE Drinking Water Objective - maximum desirable concentration
( ) - MOE Drinking Water Objective - maximum acceptable concentration
* - notification of Health Dept. with > 20 mg/L
- units in mg/L - conductance in uS - pH has no units - location are shown on Figure 24

(1) data from GLAL, 1986a
(2) data from Zenon, 1985
(3) data from MOE, 1974
(4) Data from Golder Associates, 1987

(5) Data from GLAL, 1978
(6) Data from SLSA, 1968
(7) Data from MOE, 1979
(8) Data from OWRC, 1962

Table 5 (cont'd) Chemical Analyses of Ground Water Samples in the Niagara Area

CLASS DESIGNATION	SPECIFIC ELECTRICAL CONDUCTANCE LIMITS IN uS	SUB-CATEGORY LIMITS IN uS
CLASS I (suitable under most conditions)	<1000	<250 (excellent) 250 - 750 (good) 750 - 1000 (permissible)
CLASS II (suitability dependent on soil, crop, climate, etc.)	1000 - 3000	1000 - 2000 (permissible) 2000 - 3000 (doubtful)
CLASS III (unsuitable under most conditions)	>3000	>3000 (unsuitable)

Table 6 Specific Electrical Conductance of Irrigation Waters
(after McKee and Wolf, 1963)

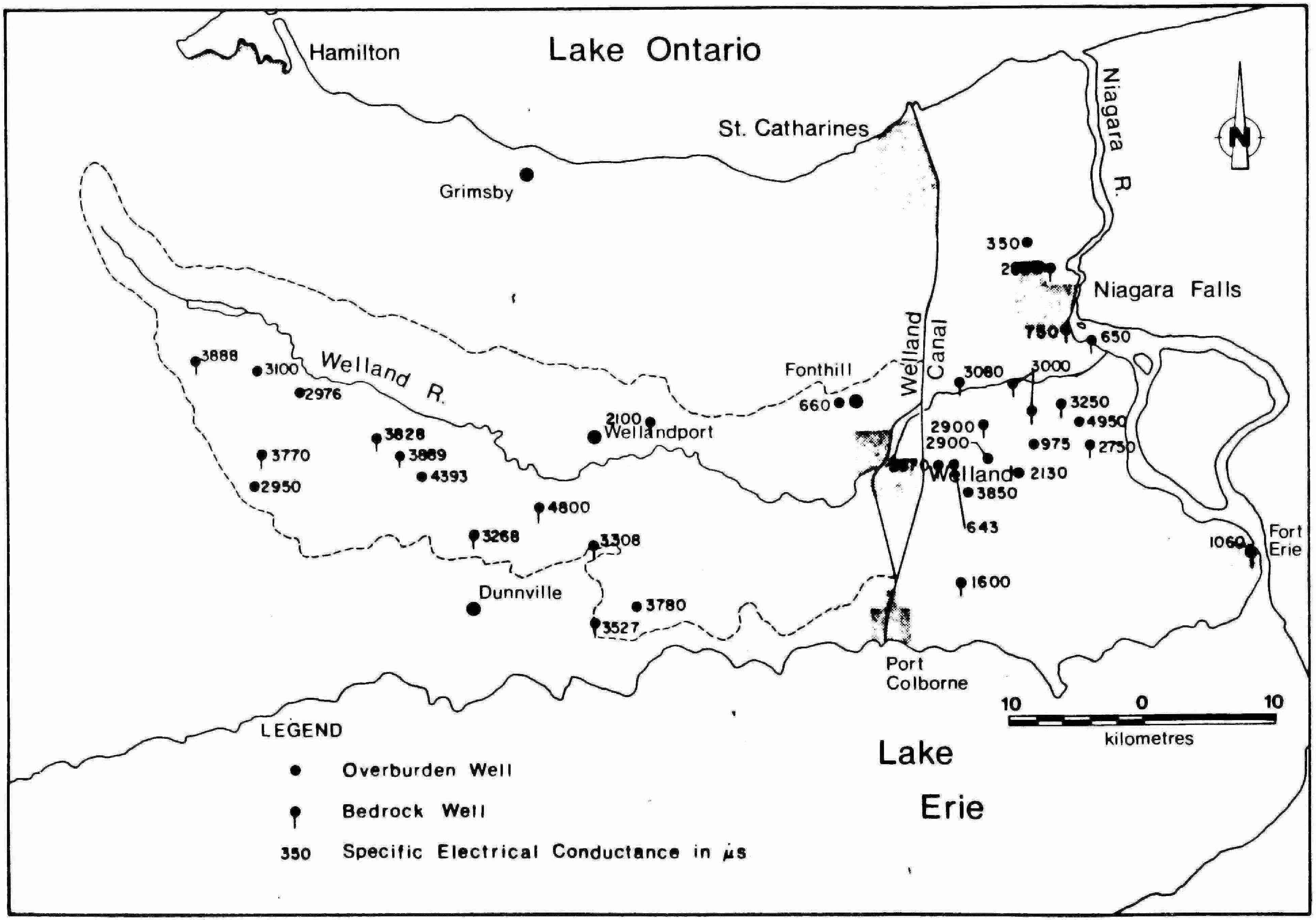
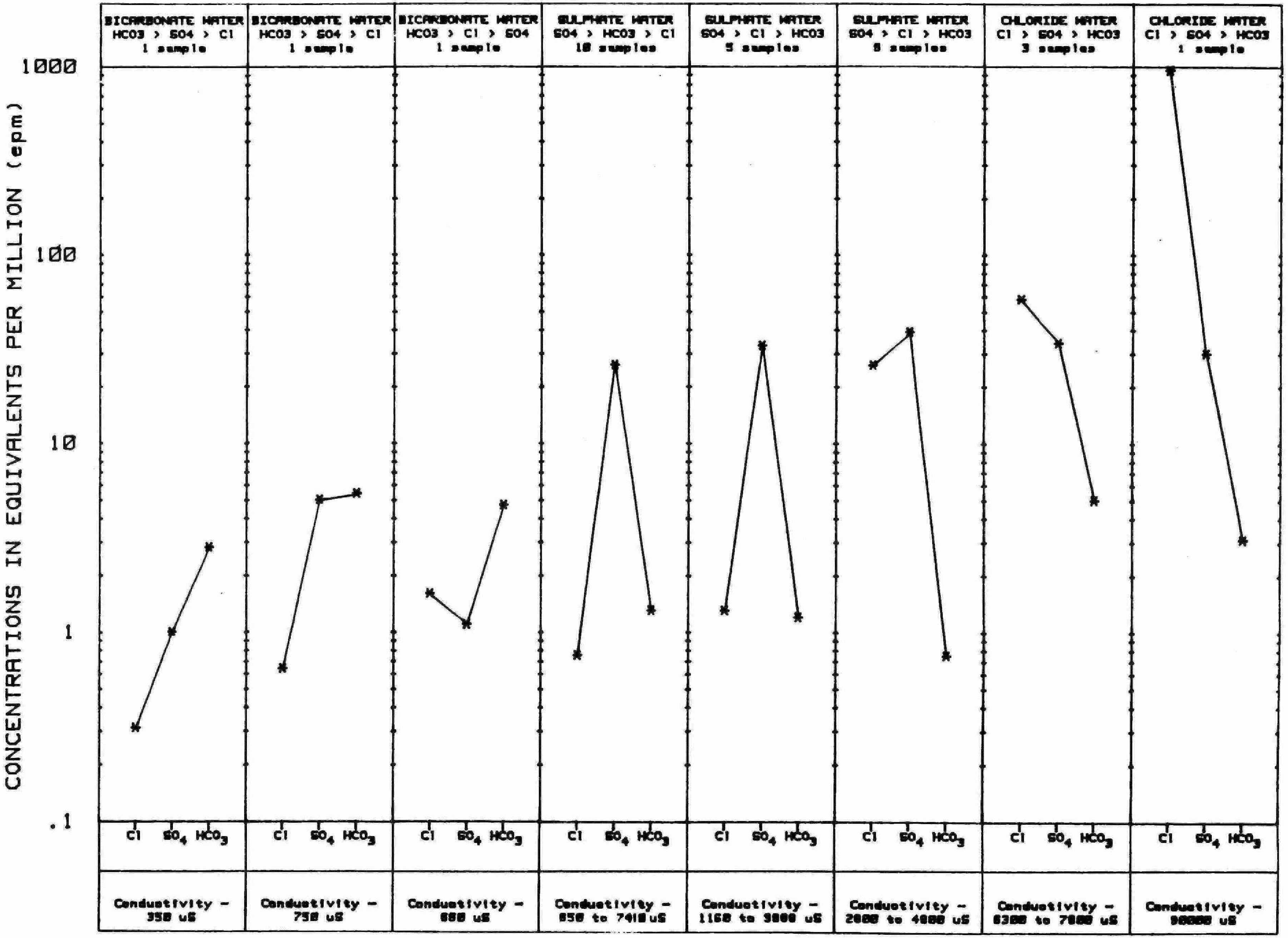


Figure 24 - Specific Electrical Conductance of Ground Water from Wells in the Niagara Area

Figure 25 - Chemical Classification of Ground Waters in the Niagara Area



Data from OWRC, 1962; MOE, 1974; GLAL, 1986a; and Golder Assoc. Ltd, 1987.

The sequence of water zonation proposed by Chebotarev (1955) was used to describe the ground waters of the bedrock aquifer in the study area. The sequence of water zonation from infiltration to natural discharge follows below:

- bicarbonate waters (HCO_3>SO_4>Cl)
- sulphate waters (SO_4>HCO_3>Cl)
- Chloride waters (Cl>SO_4>HCO_3)

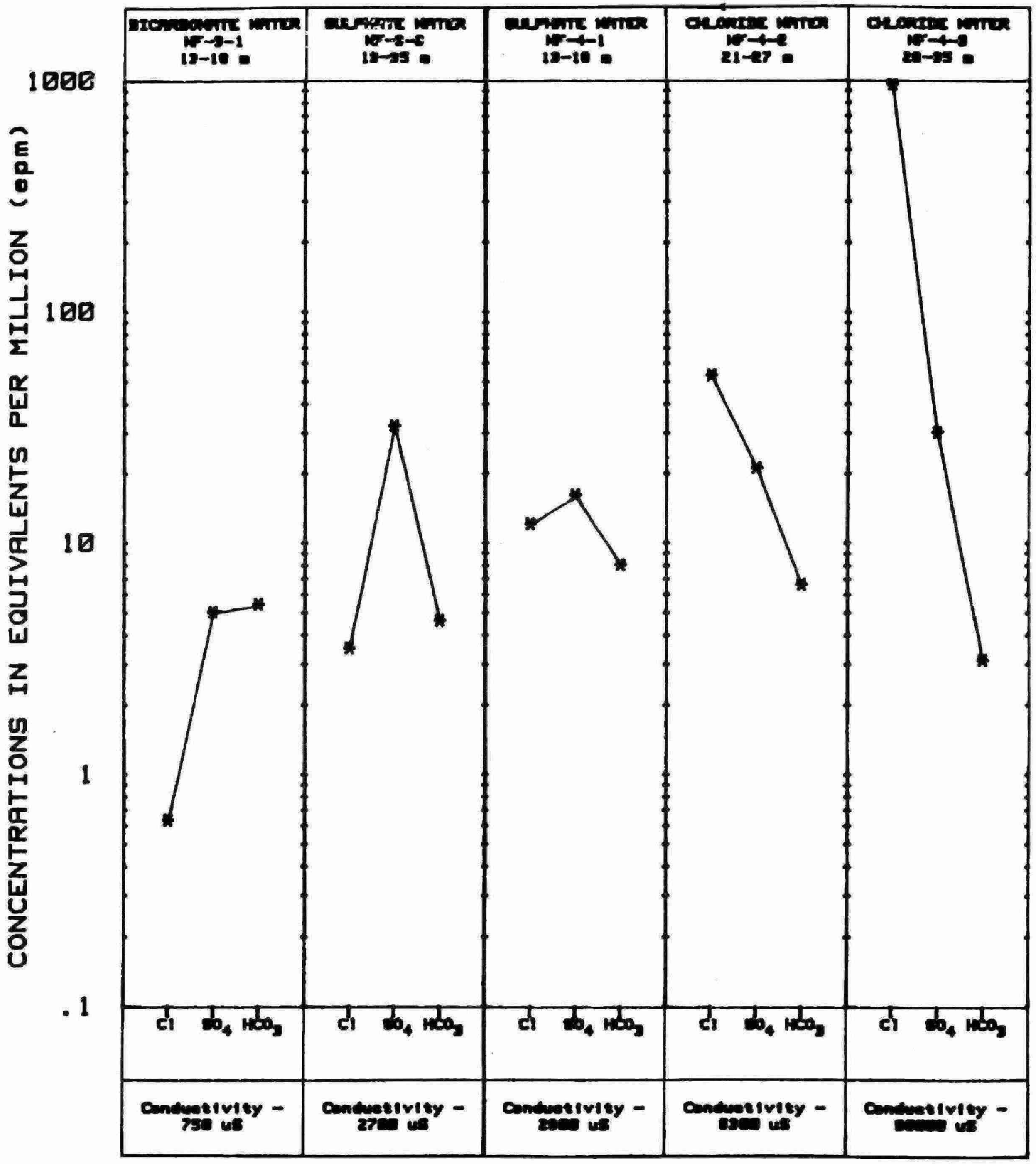
Semi-logarithmic plots, as proposed by Schoeller (1959), were used to present the chemical analysis data shown in Table 5. The water analyses were then grouped as shown in Figure 25 according to the above noted water class distinctions. Most of the ground water samples are classed as sulphate waters.

The study area is in a predominantly calcareous terrain comprised of glaciated carbonate and shale bedrock with a high content of soluble gypsum. These formations also retain large quantities of absorbed chloride and sulphate salts (Schoeller, 1959) and consequently, chemical dissolution has proceeded towards equilibrium with the materials in which the ground water circulates. The vertical progression in water class is illustrated in Figure 26 for samples collected at different depths in the same borehole at two different locations. The uppermost water sample in the two boreholes is considered to be representative of the bedrock aquifer and the lower samples from the bedrock aquitard.

In summary, ground waters in the study area are generally sulphate and chloride rich, suggesting a slow rate of ground water movement occurs permitting significant mineral dissolution to take place. Bicarbonate type waters, similar in composition to rain water, appear to be present only in those areas where more rapid ground water movement occurs, such as in those areas where the overburden aquifer is found.

The Ontario Drinking Water Objectives (MOE, 1983) are listed for the analyzed parameters listed in Table 5. Most of the samples were not analyzed for the parameters used to define the acceptable concentrations of a drinking water supply. Consequently only a cursory examination can be made of the samples used to characterize the ground water in the bedrock aquifer. For parameters related to health, fluoride exceeded the Objective on one occasion in a deep monitor near the Niagara River. Sodium does not have an Objective; however, at concentrations above 20 mg/L, it is recommended that people on sodium

Figure 26 - Vertical Chemical Progression of Ground Water in the Niagara Area



(from Zenon, 1985)

restricted diets consult their physician (MOE, 1983). Sodium concentrations exceed the 20 mg/L level significantly in most samples shown in Table 5. For parameters related to aesthetic quality, total dissolved solids exceeded the Objective consistently by about six times; hardness and sulphate by about three to five times; and iron by two to ten times. The chloride Objective of 250 mg/L was infrequently exceeded.

4.6 GROUND WATER SUSCEPTIBILITY TO CONTAMINATION

The widespread occurrence of potential contamination sources in Ontario, ranging from waste disposal sites (landfills) to accidental spills of chemicals lead the Ontario Ministry of the Environment to prepare a series of maps entitled Susceptibility of Ground Water to Contamination. These maps were designed to assist in evaluating the susceptibility of ground water to potential sources of contamination.

The intent was to flag environmental concerns with respect to ground water contamination when a specific land use development is being considered. Figures 27 and 28 (in map pocket) were compiled as continuing maps in this map series. Because of the general nature of this map series, a caution was issued with each map, that it should not be used alone to determine site specific susceptibility of ground water contamination from specific sources. It was further recommended that site specific investigations must be carried out to determine actual, local hydrogeological conditions and to relate these to specific potential contaminant sources. Further details are provided in marginal notes on the maps in this series and on Map S100 (MOE, 1980) describing the hydrogeological environments in Southern Ontario.

Figures 27 and 28 (in map pocket) are based on three hydrogeological factors considered to be most important in controlling the movement of contaminants into the ground water system;

- permeability of near-surface materials
- ground water movement
- presence of major shallow aquifers

Their combined significance was considered only qualitatively in determining the degree of susceptibility noted in the legend Figures 27 and 28 (in map pocket). Comments on the susceptibility of the hydrostratigraphic units in the study area to contamination is provided below.

4.6.1 Overburden Aquifer

The Fonthill Kame Complex northwest of Welland is highly susceptible to contamination because of the potential for obtaining high yields and the widespread use of this area as a water supply. Contaminants are likely to move to depth because of the moderate to high relief, and deeper water table in this area.

Areas of permeable glaciolacustrine sands, north and east of Dunnville, in the vicinity of Niagara Falls, and along the north shore of Lake Ontario are also susceptible to contamination. However, contaminant movement in these areas should be slow due to the low hydraulic gradient imposed on the ground water by the relatively flat topography.

4.6.2 Overburden Aquitard

The bulk of the study area is comprised of relatively impermeable glacial deposits of till, silt and clay exposed at the land surface. These deposits are not generally used as a water supply because of their low permeabilities. However, in some areas, low yields of water are obtained from storage in large diameter bored or dug wells in these deposits. Contaminants are unlikely to move appreciable distances in these deposits.

4.6.3 Bedrock Aquifer

The areas where the bedrock aquifer is within 10 m of ground surface are considered to be the most susceptible to ground water contamination. Bedrock areas within 10 m of the ground surface are found in the eastern part of the study area. The limestones and dolostones are unique because of their widespread use for water supply in the area. These areas are generally along the shore of Lake Erie, north of Fort Erie along the Niagara River, and west of Niagara Falls (Figures 27 and 28 in map pocket). Only two small areas of shale bedrock subcrop below the Niagara Escarpment and since the shale is not a major source of water supply, its susceptibility to contamination is considered to be less than that of the carbonate bedrock.

5.0 SURFACE WATER

5.1 INTRODUCTION

This chapter presents an overview of the surface water characteristics of the study area in terms of drainage, streamflow flooding, and water quality. These topics are addressed for each of the three major watersheds within the study area.

5.2 DRAINAGE

The Lake Ontario drainage system is restricted to the northern part of the Phase I study area. This drainage consists of a series of small streams which originate from the face of the Niagara Escarpment and drain northward into Lake Ontario. The average fall or flow gradient of the streams in the area draining to Lake Ontario corresponds to the regional topographic gradient of about 3 m/km. The route of many of these streams has been altered by the construction of agricultural drainage ditches.

The Welland Ship Canal is considered to be part of the Lake Ontario system. The Canal was first opened in 1829 as a barge canal with wooden locks from the Welland River to Lake Ontario. In 1833, an extension was completed to the City of Port Colborne on Lake Erie. Since then, the Canal has been rebuilt and modernized several times. The Canal provides a transportation link between Lake Erie at an elevation of about 175 m ASL to Lake Ontario at an elevation of about 76 m ASL. A lock at Port Colborne maintains the water levels at about 173 m ASL for some 22 km of canal northward to the City of Thorold. From there, a series of locks lower the water level to Lake Ontario. The last lock is at Port Weller, approximately 1 km south of Lake Ontario. Minor streams drain the adjacent land to the Canal. The most significant drainage to the Canal is in the vicinity of Thorold where tributaries up to 6 km in length drain westward into the Canal, above the Niagara Escarpment (Figure 4 in map pocket).

The portion of the Lake Erie drainage system in the study area is restricted to a narrow band of land, up to 5 km in width, along the north shore of Lake Erie (Figure 4 in map pocket). The average gradient of these small streams draining southward to Lake Erie is about 3 m/km.

The Niagara River drainage system drains the remaining study area. In the Phase I study area there are three major drainage components to the Niagara River. These are (from south to north): north-east draining streams into the upper Niagara River between Fort Erie and Chippawa; the entire Welland River system from Chippawa to Mount Hope; and minor drainage channels in the immediate vicinity of the Niagara River below the Niagara Escarpment.

The Niagara River tributaries from the Niagara Escarpment southward to Lake Erie are characterized by poor drainage due mainly to relatively flat terrain that slopes gently towards the Niagara River. The average fall of streams in this area is about 1 m/km which also includes the Welland River.

The Queenston-Chippawa Power Canal diverts water from both the Niagara and Welland Rivers. The entrance to this canal is located on the Welland River about 6 km west of the natural outlet of the Welland River at Chippawa. The Power Canal supplies the two Sir Adam Beck generating stations and the hydro reservoir south of Queenston. Its maximum capacity is 1,840 m^3/s. Flow contribution in the Power Canal is mostly from the Niagara River with only about 3% of the total flow provided by the Welland River. The relatively large contribution of Niagara River water has resulted in a reversal of natural flow in the portion of the Welland River between the Chippawa Power Canal and the Niagara River. This portion of the Welland River flows toward the west and is largely influenced by control structures on the Niagara River upstream of the Falls between Chippawa and Dufferin Island.

The Niagara River drainage system below the Niagara Escarpment is restricted to a narrow band about 1 km in width. Only minor intermittent streams drain into the Niagara River in this stretch. Most of the channels of these streams have been altered to improve agricultural drainage.

West of the Queenston-Chippawa Power Canal, the study area drains to the Welland River. Flow is generally eastward. A well-developed branched drainage pattern is evident in the upper reaches of the Welland River and its tributaries. The gradient of streams in this headwater area is in the range of 5 to 10 m/km. Low gradients, in the order of 1 m/km, prevail in the remaining part of the Welland River Basin. Major Tributaries to the Welland are Oswego Creek which joins about 6 km west of Wellandport; and Forks Creek which joins the river about 10 km east of Wellandport (Figure 3 in map pocket).

5.3 STREAMFLOW

Streams in the study area and their respective watershed drainage areas are shown in Table 7. Detailed streamflow information is available for the Welland Ship Canal, the Welland River, and the Niagara River.

No flow gauges are situated on the small streams that flow northward into Lake Ontario (e.g. One Mile Creek, Two Mile Creek, etc.). The largest stream is Four Mile Creek with a drainage area of approximately 40 km^2. Zero flows are often noted in these streams during summer months.

The Welland Ship Canal is a major flow contributor to Lake Ontario. Flow in the canal is regulated. Average flows are in the range of 226 to 241 m^3/s upstream of Allanburg (personal communication C.J. Christensen, 1984). Further to this the Water Survey of Canada published a data summary for station #02HA019 on the Welland Ship Canal at Lake Erie (Environment Canada, 1985). Data for this station were contributed by the St. Lawrence Seaway Authority. Mean annual discharge at this site for 1984 was 224 m^3/s. Flows (in terms of maximum daily flows) ranged from about 260 m^3/s in November to 120 m^3/s in March.

A small portion of the study area drains south to Lake Erie via six small intermittent streams, most of which are unnamed. No flow gauges are located on these streams; however, zero flows often occur during the summer months.

The Welland River is the major surface water feature in the Niagara River drainage area. It flows approximately 132 km from its headwaters near Mount Hope to its outlet near Chippawa.

WATERCOURSE	WATERSHED DRAINAGE AREA (square kilometres)
Welland River	880
Oswego Creek	196
Lyons Creek	87
Coyle Creek	39
Ushers Creek	21
Hunts Drain	4
Draper's Creek	5
One Mile Creek	5
Two Mile Creek	28
Four Mile Creek	40
Eight Mile Creek	14
Black Creek	72
Frenchman Creek	17
Beyres Creek	11
Shriners Creek	11
Beaver Creek	34
Lake Erie Drainage	55

Table 7 Streams and Drainage Areas in the Study Area

Streamflows in the Welland River are rather complex, due to the existence of two inverted syphons beneath the old and new Canals, the introduction of riparian flows, the operation of Ontario Hydro's Sir Adam Beck generating stations, and the Niagara River Control Structure.

Operation of the international Niagara River Control Structure by Ontario Hydro creates a reversal of flows in the lower Welland River from the Niagara River to the Queenston-Chippawa Power Canal. The lower section of the Welland River, known as Chippawa Creek actually flows upstream and diverts an average flow of 595 m^3/s from the Niagara River to the Power Canal. The low channel gradient and reversed flows create backwater conditions that may extend approximately 65 km upstream along the Welland River to the syphon at the old Welland Canal. Backwater effects are diurnal in nature and normally affect only the section between Welland and West Montrose.

Two streamflow gauging stations are maintained and operated on the Welland River by Environment Canada (Figures 3 and 4 in map pocket). Station #02HA007 is located near Caistor Corners and Station #02HA015 is located near Mount Hope. Station #02HA007 near Caistor Corners has been in operation since 1957. Due to backwater conditions in the Welland River it was not possible to establish a station further downstream. Streamflow data for these stations are published annually (Environment Canada, 1983; 1984; 1985 1986) and as a historical summary.

To obtain an appreciation of the magnitude and variability of flows in the Welland River, mean monthly discharge records were compiled for the six year period, 1981 to 1986 (personal communication P. McCurry, 1987). This time frame was selected in consultation with the Ontario Ministry of the Environment (personal communication P. Odom, 1987) to provide an overview of recent conditions as well as to coincide with the period in which detailed studies of water resources in the area were undertaken. Flows are described in terms of mean monthly discharge and mean monthly total discharge (Table 8) over the selected period. Results of high flow and low flow analyses are also reported, where available. Table 8 shows that the magnitude of mean monthly flows in the Welland River range from about 13.7 m^3/s in November, 1985 to less than 0.1 m^3/s in July, 1985.

MONTH	1981 (1)	1982 (1)	1983 (1)	1984 (1)	1985 (1)	1986 (1)	AVERAGE OF MONTHLY MEANS (2)
JAN.	0.1	3.5	2.0	0.6	2.0	1.3	1.6
FEB.	11.5	0.1	3.9	9.4	6.5	0.9	5.4
MAR.	0.9	12.0	4.4	9.0	8.8	10.0	7.5
APR.	1.2	5.7	4.4	9.3	4.1	3.6	4.7
MAY	0.8	0.2	3.8	2.1	0.1	0.4	1.2
JUNE	0.9	2.1	0.6	4.7	0.1	0.4	1.5
JULY	0.7	0.1	0.5	0.1	0.0	0.7	0.4
AUG.	1.9	0.1	1.9	0.1	0.2	0.3	0.8
SEPT.	4.1	0.6	0.6	1.8	0.2	1.2	1.4
OCT.	3.2	0.6	0.9	0.6	1.8	2.8	1.7
NOV.	2.3	5.5	3.4	1.8	13.7	4.0	5.1
DEC.	2.9	8.2	6.8	4.3	3.7	6.2	5.4

NOTES :

1. All flows reported in units of cubic metres per second rounded to the nearest tenth.
2. Average of mean monthly flows for the 1981-1986 period.

Table 8 Mean Monthly Discharge for Station #02HA007 (1981-1986)

An analysis of high flows was conducted by Dillon (1985). This analysis showed that storms produced a two day rise period in the hydrograph. The recession period was less steep, lasting three to four days. Instantaneous peak flows were generally 7% higher than the mean daily values.

An analysis of low flows for the 20 year period 1962 to 1981 was undertaken by the Water Resources Branch of the Ontario Ministry of the Environment (Personal communication J. Eddie, 1987). The analysis used June 1 to November 30 data only and indicated zero flows for all categories examined, including the seven-day low flows (2, 5, 10 and 20 years) and duration flows (95%, 98% and 99%). A seven-day low flow such as the $7^{Q}20$ is defined as the low flow sustained for a seven day period that has a 5% chance of occurring in any given year. A duration flow such as the 95% duration flow is the daily flow that was equaled or exceeded 95% of the time during the period of record analyzed.

A low flow analysis for the 19 year period 1963 to 1981 was undertaken by Dillon (1985). This analysis reported that on the average, 42 days in every year, the flow drops to 0.001 m^3/s or below. Extreme low flow periods were observed generally during the summer months of June, July, and August.

The mean monthly flows for the 1981 to 1986 period are shown graphically in Figure 29, to provide an appreciation of streamflow variability within a year. This Figure shows that maximum discharges usually occur from November to April, while minimum discharges usually occur from May to October. March usually has the highest flows and July the lowest flows.

Station #02HA015 near Mount Hope was installed in 1980. This gauge measures flows for a 2.08 km^2 drainage area in the headwaters of the Welland River basin. The mean monthly flow for the period 1982 to 1986 is contained in Table 9 (data for 1981 have not been published by Environment Canada). Although the magnitude of flows are much smaller in comparison to the Caistor Corners gauge the pattern of maximum and minimum flows is similar. Maximum flows are observed from November to April with

MONTH	1982 (1)	1983 (1)	1984 (1)	1985 (1)	1986 (1)	AVERAGE OF MONTHLY MEANS (2)
JAN.	0.009	0.006	0.004	0.007	0.010	0.007
FEB.	0.004	0.022	0.087	0.089	0.007	0.042
MAR.	0.124	0.038	0.056	0.108	0.092	0.084
APR.	0.036	0.032	0.071	0.030	0.020	0.038
MAY	0.002	0.026	0.019	0.003	0.019	0.014
JUNE	0.016	0.007	0.101	0.004	0.005	0.027
JULY	0.000	0.008	0.002	0.002	0.006	0.004
AUG.	0.002	0.012	0.001	0.003	0.008	0.005
SEPT.	0.004	0.002	0.036	0.001	0.011	0.011
OCT.	0.002	0.007	0.002	0.007	0.017	0.007
NOV.	0.023	0.020	0.018	0.077	0.022	0.032
DEC.	0.050	0.038	0.022	0.023	0.039	0.034

NOTES :

1. All flows reported in units of cubic metres per second rounded to the nearest thousandth.
2. Average of mean monthly flows for the 1982-1986 period

   (data not published for 1981).

Table 9 Mean Monthly Discharge for Station #02HA015 (1982-1986)

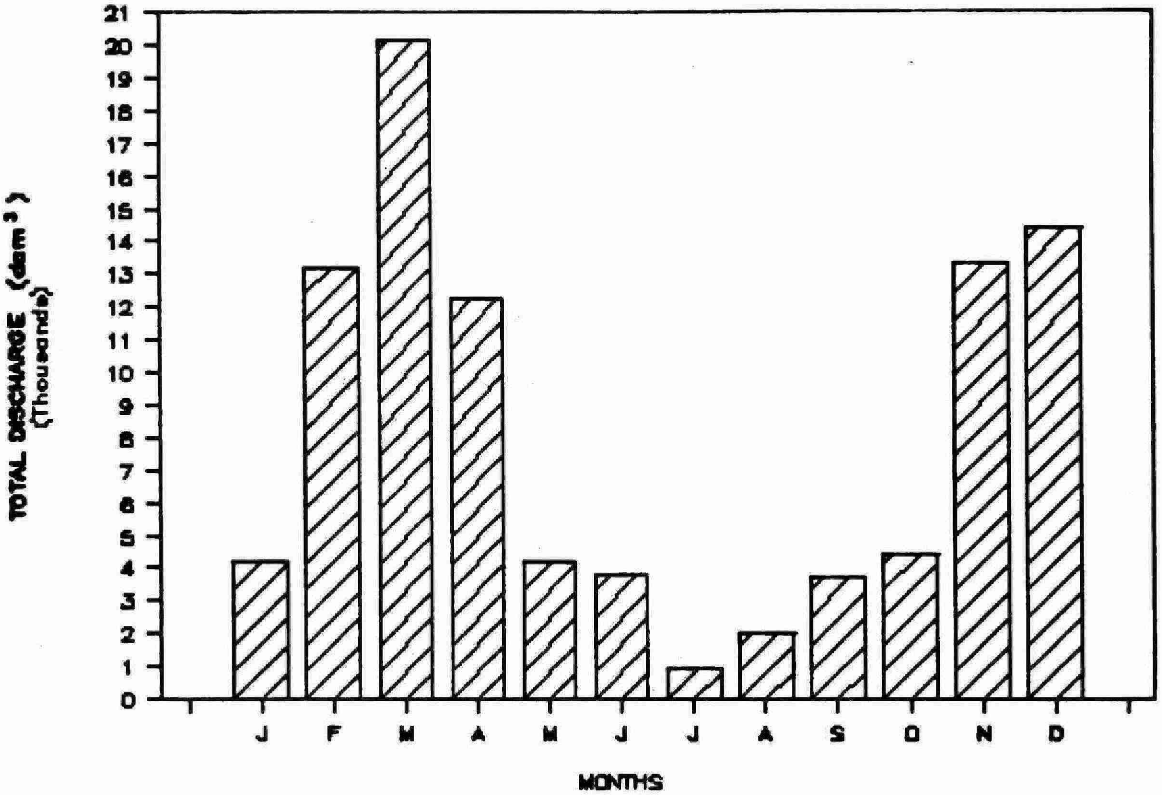


Figure 29: Mean Monthly Total Discharge for Station #02HA007 Near Caistor Corners (1981-1986)

March having the highest flows. Minimum flows are observed from May to October with July having the lowest flows. Due to the short period of record no low flow or high flow analyses have been undertaken for this station. Zero flows have often been recorded for several days during the summer months. For example, during the 92 day period from July 1 to September 30, zero flows were recorded as follows:

- 75 days in 1982,
- 33 days in 1983,
- 39 days in 1984,
- 23 days in 1985, and
- 0 days in 1986

Dillon (1985) reported that snow melt peak flows recorded at the Mount Hope gauge, produced peaks 24 hours later at the downstream Caistor Corners gauge.

5.4 FLOODING

Flooding is a serious concern in the study area. There is a history of floods which dates well back into the 1800s (DOE, 1972). The Welland River is the stream most noted for flooding in the study area with six major floods recorded over the past 50 years. Delineation of flood vulnerable areas and investigation of flood remedial measures were undertaken by Dillon (1985) on the Welland River.

5.5 WATER QUALITY

5.5.1 Special Studies

Water quality in the Niagara Region has long been an important issue. In recent years several special studies have been undertaken to investigate water quality particularly in regard to toxic chemicals. For example, studies of the Niagara river include an assessment of toxic chemicals and their sources (Niagara river Toxics Committee, 1984; Marsalek et al., 1983) and an evaluation of Niagara River monitoring data (Data Interpretation Committee, 1986). A partial listing of local water quality studies includes:

- Lyons Creek (Brock University, 1986)
- Niagara River tributaries (MOE, 1986)
- Welland River (OWRC, 1965; Johnson, 1964; Dillon, 1985)

- Niagara Peninsula (DOE, 1972; Brock University, 1979; MOE, 1982a)
- Lake Erie (IJC, 1985).

Early reports on water quality in the Welland River documented a deterioration of water quality and attributed this to a change from agricultural to urban and industrial land uses (DOE, 1972).

An analysis of water quality data collected at Ontario Ministry of the Environment provincial water quality stations from 1974 to 1978 (O'Neill, 1982), identified that the Provincial Water Quality (PWQ) Objectives (MOE, 1978a) were often exceeded for some of the parameters examined, e.g., total phosphorus and fecal coliform. Eighty-five to 100% of samples analyzed for total phosphorus exceeded the provincial guideline of 0.030 mg/L. Fecal coliform non-compliance with the PWQ Objective (100 counts/100 mL) ranged from 13% to 100%. Most stations were generally found to be in compliance with the dissolved oxygen PWQ Objective. Similarly, a review of water quality data on the Welland River (1968-1984) by Dillon (1985) found that the PWQ Objectives were often exceeded for fecal coliforms and phosphorus.

A 1983 study of Canadian tributaries to examine trace constituents in water and sediment (Hart, 1986) identified nitrates and several metals above PWQ Objectives.

5.5.2 Routine Studies

In addition to the special studies mentioned above, routine data collection has been carried out since 1964 through the Ontario Ministry of the Environment's Provincial Water Quality Monitoring Program. A total of 22 water quality stations have been operated on the Welland River, the Welland Ship Canal, and Eight Mile Creek (personal communication S. Harangozo, 1987). Presently, eight water quality stations are active in the area (Table 10); The locations of the active and discontinued water quality stations are shown in Figures 3 and 4 (in map pocket). Table 10 contains a listing of water quality stations, their period of record and whether they are active or discontinued.

STATION	WATER BODY	LOCATION	STATUS	PERIOD OF RECORD	DRAINAGE AREA (square km)
6-1-1-2	One Mile Creek	Niagara On The Lake	D	1964 - 71	4
6-2-1-2	Two Mile Creek	Lakeshore Road	D	1964 - 71	28
6-3-1-2	Four Mile Creek	Lakeshore Road	D	1964 - 71	40
6-3-2-2	Four Mile Creek	Third Line Road	D	1965 - 71	25
6-3-3-2	Four Mile Creek	Seventh Line Road	D	1965 - 71	16
6-3-4-2	Four Mile Creek	Downstream St. Davids	D	1965 - 71	6
6-3-5-2	Four Mile Creek	First Concession	D	1972 - 76	33
6-5-1-2	Six Mile Creek	Lakeshore Road	D	1964 - 76	21
6-10-1-2	Eight Mile Creek	Lakeshore Road	D	1964 - 76	14
6-14-1-2	Welland Ship Canal	Weir Near Lakeshore Road	A	1964 - 87	N/A
6-14-2-2	Welland Ship Canal	Near Lake Erie	A	1966 - 71, 73 - 87	N/A
11-1-1-2	Chippawa Canal	Whirlpool Road	D	1972 - 73, 74 - 83	N/A
11-1-2-2	Chippawa Canal	Lundy's Lane	D	1972 - 73	N/A
11-1-3-2	Welland River	Montrose Bridge	D	1965 - 80	780
11-1-3-83	Welland River	Montrose Bridge	A	1980 - 87	780
11-1-4-82	Welland River	Bridgewater Street	D	1964 - 75	880
11-1-5-2	Welland River	Port Robinson	A	1965 - 87	620
11-1-6-2	Welland River	Welland	D	1977 - 78	600
11-1-7-2	Welland River	Near Welland Airport	A	1977 - 87	580
11-1-8-2	Welland River	Sinclairville Bridge	A	1978 - 87	60
11-1-9-2	Welland River	Former Twp. of Binbrook	A	1978 - 87	26
11-1-10-2	Welland River	Hydro Footbridge	A	1982 - 87	N/A

NOTE : D = Discontinued
A = Active

Table 10 - Water Quality Stations in the Niagara Area

Six of the eight currently active stations are located on the Welland River. Stations 11-1-8 and 11-1-9 are located in the upper reaches of the Welland River and are representative of agricultural conditions. Station 11-1-7 is located on the Welland River south of the Welland Airport. This station represents primarily agricultural conditions upstream. Station 11-1-5 is located at the New Syphon at Port Robinson and is representative of mixture of upstream agricultural and urban inputs. Station 11-1-3 is located at the mouth of the Welland River. Station 11-1-10 is situated at the Hydro footbridge downstream of Whirlpool Road and is representative of Niagara River Water (primarily). Stations 6-14-1 and 6-14-2 are located on the Welland Ship Canal. Station 6-14-2 is situated at the first bridge downstream from Lake Erie and station 6-14-1 is located at the weir downstream from Lakeshore Road near Lake Ontario.

An overview analysis of water quality data for the eight currently active stations on the Welland River and Welland Ship Canal was undertaken to provide insight into general water quality and spatial variability. Data from 1982 to 1986 (personal communication B. Whitehead, 1987) were compiled for 16 water quality parameters.

The analysis (see Appendix A) consisted of the calculation of basic statistics such as mean parameter concentration/level, maximum, minimum, number of samples. The mean concentration/level of the sixteen parameters analyzed are summarized in Table 11 and discussed briefly below.

Alkalinity

Alkalinity is a measure of the water's capacity to neutralize an acid. Waters with high alkalinity (>500 mg/L) are undesirable due to excessive hardness. Mean alkalinity varied from 136 mg/L at station 11-1-9 (upstream) to 94 mg/L at station 11-1-3 (downstream). The two stations in the upper reaches of the Welland River basin (i.e., 11-1-8 and 11-1-9) had slightly higher mean alkalinity levels than at other stations.

Chloride

Chloride is a naturally occurring substance found in all waters. Chloride is also present in sewage, storm drainage, industrial waste, and road salt. At high levels (i.e., >250 mg/L), chlorides are a concern in water used for drinking and irrigation.

PARAMETERS (1)	WELLAND SHIP CANAL		WELLAND RIVER					
	L. ERIE	L. ONTARIO	UPSTREAM					DOWNSTREAM
	6-14-2	6-14-1	11-1-9	11-1-8	11-1-7	11-1-5	11-1-3	11-1-10
Alkalinity	100	103	136	128	105	99	94	98
Chloride	16.7	20.4	42.9	47.5	27.0	19.9	19.9	16.3
Conductivity (2)	297	321	581	675	460	338	358	294
Copper	0.003	0.005	0.007	0.009	0.005	0.005	0.007	0.004
Dissolved Oxygen	10.2	10.8	8.5	8.7	8.1	9.43	9.9	9.7
Fecal Coliforms (3)	14	30	128	217	174	2240	800	950
Fecal Streptococci (3)	14	19	177	307	137	340	146	276
Field pH (4)	8.17	8.09	7.66	7.73	7.70	7.89	7.90	8.21
Total Ammonia	0.021	0.062	0.156	0.112	0.210	0.211	2.064	0.146
Nitrate & Nitrite	0.267	0.404	1.266	1.367	1.508	0.864	2.132	0.411
Total Kjeldahl Nitrogen	0.274	0.351	0.901	1.038	1.510	0.847	4.264	0.509
Lead	0.005	0.009	0.008	0.009	0.004	0.006	0.006	0.006
Phenols (5)	1.0	4.0	1.0	0.6	0.7	1.0	1.0	0.4
Total Phosphorus	0.027	0.044	0.157	0.188	0.241	0.120	0.154	0.035
Suspended Solids	8.3	22.4	59.8	90.4	45.9	30.1	32.2	12.5
Zinc	0.004	0.013	0.087	0.015	0.022	0.014	0.016	0.006

NOTES :

(1) All units mg/L unless otherwise noted
(2) uS
(3) counts / 100 mL - geometric mean
(4) no units
(5) ug/L

Table 11 - Mean Concentration/Level for the 1982-1986 Period

Stations 11-1-8 and 11-1-9 in the upper reaches of the Welland River had the highest mean chloride levels (47.5 mg/L and 42.9 mg/L, respectively). The remaining stations showed little variability, ranging from 27.0 mg/L at station 11-1-7 to 16.3 mg/L at station 11-1-10.

Specific Electrical Conductance

Specific electrical conductance or conductivity provides a measure of the electrolytic properties of water and is indicative of the presence of dissolved ions such as chloride, sulphate, and calcium.

Stations 11-1-8 and 11-1-9 had the highest mean conductivity levels (675 uS and 581 uS, respectively). The remaining stations ranged from 294 uS at station 11-1-10 to 460 uS at station 11-1-3.

Copper

Copper salts are found at trace levels in natural surface waters and at elevated levels due to man's activities, primarily industrial discharges.

Very little variability was observed for mean copper concentrations. Station 6-14-2 on the Welland Ship Canal (Lake Erie) had the lowest mean concentration (0.003 mg/L) and station 11-1-8 on the Welland River (upper reaches) had the lowest (0.009 mg/L).

Dissolved Oxygen

Dissolved oxygen is necessary for fish and other aquatic life in surface waters. Organic wastes and some inorganic material consume oxygen upon decomposition which may deplete oxygen levels required by aquatic life. It should be noted that dissolved oxygen levels are normally measured during the daytime and that at night, dissolved oxygen levels may be lower.

The mean dissolved oxygen levels varied from a high of 10.8 mg/L at station 6-14-1 on the Welland Ship Canal to a low of 8.1 mg/L at station 11-1-7 on the Welland River upstream of the City of Welland.

Fecal Coliform and Fecal Streptococci

Fecal coliform and fecal streptococci organisms are bacteria found in the digestive tract of water blooded animals. Their presence in surface waters are an indication of sewage or fecal contamination by warm blooded animals.

Bacteriological levels (in terms of geometric means) were highest at station 11-1-5 on the Welland River near the new syphon at Port Robinson. The geometric means of samples collected between 1982 and 1986 at this station were 2,240 counts/100 mL for fecal coliforms and 340 counts/100 mL for fecal streptococci. Bacteriological levels at the remaining stations in the Welland River were also high, 950 fecal coliform organisms/100 mL at station 11-1-10 to 128 counts/100 mL at station 11-1-9.

Bacteriological levels in the Welland Ship Canal were much lower than the Welland River, i.e., 30 fecal coliform counts/100 mL at station 6-14-1 and 14 counts/100 mL at station 6-14-2. Fecal streptococci levels were similarly lower than the Welland River stations.

pH (Field pH)

pH is an index of the acidity of surface waters. Natural waters normally have pH in the range of 6.5 to 8.5.

The mean field pH varied from 8.21 at station 11-1-10 to 7.66 at station 11-1-9.

Ammonia

Total Filtered Reactive Ammonia nitrogen is the dissolved product of the anaerobic decomposition of organic matter. Generally, surface water with poor water quality have ammonia levels greater than 0.1 mg/L (MOE, 1982a). Due to problems with laboratory analysis between 1981 and 1983 only 1984- 1986 data were included in this analysis.

The mean concentration of ammonia was greatest (2.064 mg/L) at station 11-1-3 (Welland River at the Montrose Bridge) and lowest at the Welland Ship Canal (0.062 mg/L at station 6-14-1 and 0.021 mg/L at station 6-14-2).

Only the Welland Ship Canal and stations 11-1-8 and 11-1-9 (Welland River upper reaches) had mean filtered ammonia levels less than 0.1 mg/L.

Filtered Nitrite and Nitrate ($NO_2 + NO_3$)

Nitrite is an intermediate oxidation product of ammonia. Nitrate is the end product of the stabilization of organic nitrogen. Nitrogen in the nitrate form is readily utilized by aquatic plants and algae.

The pattern of mean NO_2+NO_3 concentrations at the eight active stations studied is similar to that observed for filtered ammonia. The highest mean concentration was observed at station 11-1-3 (2.132 mg/L). The Welland Ship Canal stations were lowest (0.267 mg/L at 6-14-2 and 0.404 mg/L at 6-14-1).

Total Kjeldahl Nitrogen

Total Kjeldahl nitrogen is a measure of the total nitrogen matter present, excluding nitrate and nitrite forms. The normal range for total Kjeldahl nitrogen in surface waters is considered to be 0.1 to 0.5 mg/L (MOE, 1982a).

The pattern of mean concentrations of total Kjeldahl nitrogen is similar to that observed for filtered ammonia and filtered nitrite plus nitrate. The highest mean concentration was observed for station 11-1-3 (4.264 mg/L) and the lowest for stations 16-14-2 (0.274 mg/L) and 16-14-1 (0.351 mg/L) on the Welland Ship Canal.

Only the Welland Ship Canal stations and station 11-1-10 at the Hydro Footbridge downstream of Whirlpool Road had mean concentrations less than 0.5 mg/L.

Lead

Lead may occur at low levels naturally in some streams and/or it may be introduced as a result of industrial discharges and deposition from automobile exhaust. Lead is a cumulative poison that may be toxic to fish and aquatic life and (in drinking water) to humans.

The Provincial Water Quality Monitoring Network data for Lead contained a significant amount of "less than" detection limit data. In calculating means "less than" data were incorporated as "actual" data. As a result the reported mean concentrations for lead should be considered to be an over stimulation of the true mean concentration.

The mean lead concentration was highest for stations 11-1-8 and 11-1-9 in the upper reaches of the Welland River (0.009 mg/L and 0.008 mg/L, respectively). The lowest mean concentrations were observed at station 11-1-7 (0.004 mg/L)

Reactive Phenolics

Phenolics are derived from many industrial processes and may also be released from aquatic plants and decaying vegetation. Phenolics may be toxic to fish and may taint fish flesh.

The reactive phenolics test indicates only certain phenolic compounds. Other phenolic compounds may be present. The Provincial Water Quality Monitoring Networks data for phenolics contained a significant amount of "less than" detection limit data. In calculating means "less than" data were incorporated as "actual" data. As a result the mean concentration for phenolics should be considered to be an overestimation of the true mean.

The highest mean phenolics concentration was observed for station 6-14-1 at the outlet of the Welland Ship Canal to Lake Ontario (4.0 ug/L). The remaining stations had mean concentrations equal to or less than 1 ug/L, with station 11-1-10 (Welland River at Ontario Hydro Footbridge) having the lowest mean concentration (0.4 ug/L).

Total Phosphorus

Total phosphorus is a nutrient for plant and animal life. It may occur naturally in both organic and inorganic forms. It may be introduced to surface water through sewage, industrial discharges, urban drainage, and agricultural drainage. Phosphorus levels in rivers above 0.030 mg/L may cause excessive plant growth.

From Table 10 it can be seen that the mean concentrations exceed 0.030 mg/L level at all stations except station 6-14-2 on the Welland Ship Canal which represents Lake Erie water. Generally, all of the stations on the Welland (except for 11-1-10 on the Power Canal) have high total phosphorus levels.

Suspended Solids

Suspended solids are a measure of undissolved, solid material in surface waters.

Suspended solids may be a result of natural erosion processes, which in some cases may be accelerated due to construction, urbanization, extensive agriculture, and banks destabilization. Suspended solids may also be introduced as a result of sewage and industrial discharges.

Mean suspended solids concentrations vary from 90.4 mg/L at station 11-1-8 to 8.3 mg/L at 6-14-2. Suspended solids are generally higher in the Welland River (except station 11-1-10 on the Power Canal) than in the Welland Ship Canal.

Zinc

Zinc may occur naturally in waters at trace levels. It may be introduced to surface waters through urban drainage and industrial discharge.

The highest zinc level occurred at 11-1-9 in the upper reaches of the Welland River (0.087 mg/L). Mean Zinc levels at the other stations were lower ranging from 0.022 mg/L at station 11-1-7 to 0.004 mg/L at station 6-14-2.

6.0 HYDROLOGIC BUDGET

A water balance has been prepared for the study area based on long term climatological data from the Welland meteorological station. It is based on the balance of precipitation (P), evapotranspiration (ET), and a water surplus (WS). The equation is:

$$P = ET + WS$$

The water surplus term includes the following three components:

- surface runoff and streamflow (RO)
- baseflow - shallow ground water flow to surface water systems (BF)
- ground water recharge to deeper aquifers (GWR)

Thus the water balance equation can be rewritten as follows:

$$P = ET + RO + BF + GWR$$

For purposes of the following discussions, the Welland meteorological station was chosen to be representative of climatological conditions in the study area because of its central location. The individual components of the water balance are addressed with respect to the climatological data from the Welland station in greater detail below.

6.1 PRECIPITATION

Precipitation in the context of the following discussion is total precipitation and includes both snowfall and rainfall. Precipitation is highly variable on a daily or monthly basis; but the variability is reduced considerable when it is considered on an annual basis. For example, within the six-year period from 1981 to 1986, the monthly precipitation at Welland was quite variable and ranged, by a factor of about 17, from a minimum of 14 mm in October 1984 to a maximum of 233 mm in November 1985. However, for this same six-year period, annual precipitation only varied by a factor of about 1.3, from a minimum of 939 mm in 1981 to a maximum of 1,201 mm in 1985 (Figure 30). The mean annual precipitation from 1981 to 1986 was 1,045 mm, approximately 11% greater than the 938 mm long-term mean annual based on 30 years of meteorological record from 1951 to 1980 (Environment Canada, 1982).

6.2 EVAPOTRANSPIRATION

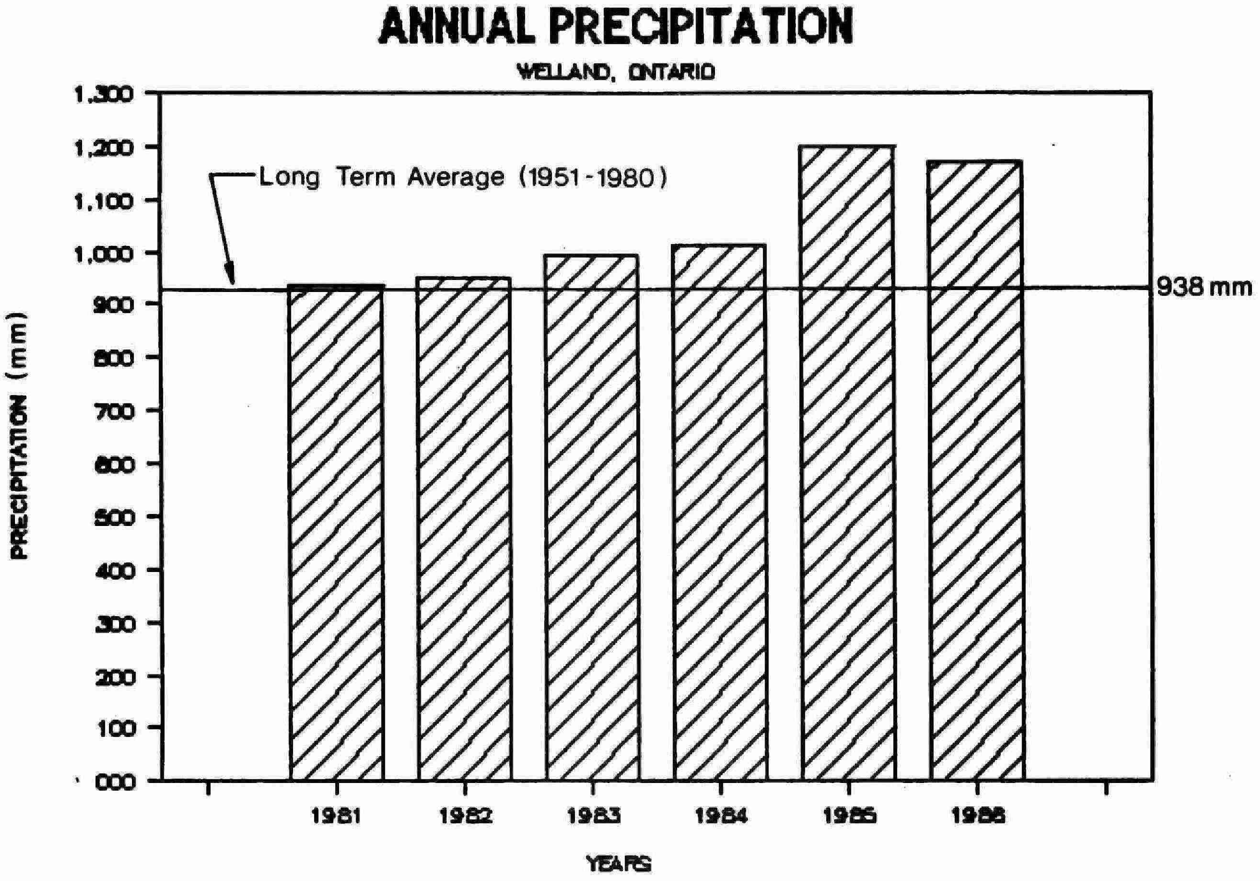
Evapotranspiration in the context of the following discussion refers to evaporation and transpiration processes that return water as vapour to the atmosphere. The implication is that the water is either converted to vapour and discharged to the atmosphere or stored as a consumptive use in plant tissue.

Evapotranspiration was estimated at 551 mm/a for the Welland meteorological station during the period 1981 to 1986 using the method outlined by Thornthwaite and Mather (1957). This method determines evapotranspiration from climatic data. The parameters are temperature, length of day, and a fixed sharing of the heat budget between heating the air and evaporation. A soil moisture storage of 50 mm in the evaporative zone of the soil was also assumed. Evapotranspiration values for this six-year period are shown below:

Year	Evapotranspiration (mm)
1981	570
1987	528
1983	507
1984	555
1985	534
1986	616
AVERAGE	551

The average evapotranspiration for this six year period of 551 mm/a is about 5% higher than the 30 year long-term average of 525 mm/a for 1951 to 1980.

Figure 30 - Mean Annual Precipitation at Welland (1981-1986)



(Provisional data from Environment Canada, Atmospheric Environmental Services)

6.3 WATER SURPLUS

The water surplus in the context of the following discussions is the water remaining from precipitation after accounting for evapotranspiration and transpiration processes. The water surplus is shown in Table 12 for the six-year period from 1981 to 1986. The six-year average of 494 mm/a is approximately 20% higher than the 413 mm/a average for the 30 year period from 1951 to 1980.

The water surplus can be further subdivided between surface runoff, including baseflow, or ground water recharge. In an urban setting, most of the water surplus is runoff from paved or otherwise impervious surfaces. In a rural setting the water surplus may have an infiltration component, depending on local soils and slopes. The infiltration component can be further subdivided into the shallow and deep ground water flow systems. The shallow ground water flow system is defined as the water comprising baseflow in the local stream system. Hence it can be measured as part of the streamflow at a gauging station. The net result is that the total annual streamflow at a gauging station can be subtracted from the water surplus in that watershed to give an indication of the amount of water that flows into the deeper ground water flow system.

6.4 INFILTRATION

Streamflow records from the Federal Gauge #02HA007 on the Welland River at Caistor Corners indicate that the mean annual discharge for the period 1981 to 1986 in the Welland River was the equivalent of 419 mm/m^2 of catchment. Assuming that this value is representative of the whole basin, then the average surplus of 494 mm/m^2 (Table 12) would leave a net basin-wide discharge to the deep ground water flow system of approximately 75 mm/a.

The streamflow record is intermittent from 1956 and is not directly comparable to the long-term (1951-1980) precipitation record used in the preceeding discussions. Nevertheless it is assumed that the long-term infiltration will be less than 75 mm/a because the annual precipitation for 1981 to 1986 was 11% higher than the long-term average. The value of 75 mm/a can be considered to be a conservative estimate for maximum infiltration to the deep ground water system.

YEAR	PRECIPITATION (mm) *	EVAPO-TRANSPIRATION (mm)	SURPLUS (mm)
1981	939	570	369
1982	950	528	422
1983	995	507	489
1984	1,012	555	457
1985	1,201	534	668
1986	1,173	616	557
AVERAGE	1,045	552	494
1951-1980 AVERAGE	938	525	413

* Long term data have been used in place of missing data for October, 1982. The data from October to December, 1986, are provisional.

Table 12 Water Balance for Welland, Ontario (1981-1986)

The total infiltration to the deep ground water system in the Phase I study area (709 km^2)is estimated at about 1.7 m^3 using the infiltration estimate of 75 mm/a. Similarly, infiltration in the Phase II study area (899 km^2) is estimated at about 2.1 m^3/s. Thus total recharge to the bedrock aquifer underlying the Phase I and Phase II areas is about 4 m^3/s. This value compares to domestic water withdrawals of about 0.3 m^3/s from water wells in the study area (assuming a rural population of 50,000 and a usage of 500 litres per day per person); or to the 1.7 m^3/s capacity of the water treatment facility (MOE, 1986) for the City of Niagara Falls; or to a flow of about 5,692 m^3/s in the Niagara River at Queenston.

7.0 WATER USE

7.1 INTRODUCTION

Water use in the study area is categorized and discussed, according to the principal water uses. These include industrial, municipal, agricultural, recreational, and rural domestic use. Water use in the study area is a reflection of the distinctly different land use patterns. The western half (Phase II) is mainly rural and the eastern half (Phase I) a mixture of urban, agricultural, and rural land use.

The major sources of information consulted include the Ontario Ministry of the Environment's Permit To Take Water (PTTW) files, water resources reports, and West Central Region technical files; Niagara Conservation Authority reports; Ontario Waste Management Corporation studies; consultant reports; university studies; and reports of the former Ontario Water Resources Commission. Specific information has also been obtained in discussions with individuals with the Ontario Ministry of the Environment, the St. Lawrence Seaway Authority and the Regional Municipality of Niagara. The PTTW takings are mapped and shown on Figures 31 and 32 (in map pocket). All available permits were examined but only permits that were current at the time of this study were compiled. A permit for water use is only required where more than 50 000 litres per day are used. Permitted water use may occur on a year round basis as is common with municipal or industrial uses or on a seasonal basis as with agricultural uses such as irrigation. The total amount of permitted water takings in both the Phase 1 and Phase 2 study areas is about 3.2 m^3/s.

7.2 PHASE I - WATER USE

Water use in the Phase I area is varied. It includes, in decreasing order of permitted use, industrial, municipal, agricultural, recreational, and rural domestic use. Only the larger water users (i.e., greater than 50 000 litres per day require a permit. This generally does not apply to rural domestic use. A summary of the water use permits is shown in Table 13. The largest permitted use is industrial followed by municipal, agricultural, and recreational. The total permitted use is 2.7 m^3/s. This does not include a number of large municipal water users that established water use prior to the Ontario Ministry of the Environment's water use permit system. This includes the municipalities of St. Catharines, Thorold,

Source	Municipal	Agricultural	Industrial	Recreational	Totals
Ground Water	0.0844	0.0040	0.1535	0.0196	0.2615
Surface Water	0.6798	0.1972	1.4210	0.1093	2.4073
Total	0.7642	0.2012	1.5745	0.1289	2.6688

NOTE : Units in cubic metres per second
* includes permitted water use only

Table 13 Water Use in the Phase I Study Area*

Welland, Niagara Falls, and Fort Erie, as well as small communities served by the St. Catharines Decew water treatment facilities, including Niagara-on-the-Lake, Virgil, St. Davids, and Queenston.

7.2.1 Municipal

There are several major urban centres within the Phase I study area. The majority of these rely on surface water supplies. The village of St. Davids has a ground water source for backup up to the surface water source. A summary of Municipal supplies is provided in Table 14.

The Welland Ship Canal is a major source of water and serves the municipalities of Welland, Port Colborne, Port Robinson and the St. Catharines (Decew) water supply system. The St. Catharines (Decew) water supply system serves a number of communities including St. Davids, St. Catharines, Niagara-on-the-Lake, Virgil, Queenston, and the Town of Lincoln communities of Vineland and Jordan (personal communication K. Williams, 1987).

The Town of Fort Erie is the only large community that obtains water directly from Lake Erie. Small communities along the Lake Erie shore as well as numerous individual homes and cottages also rely on Lake Erie as a source of water.

The City of Niagara Falls obtains municipal water supplies directly from the mouth of the Welland River at Chippawa (Niagara River water).

The majority of the municipal water taking do not fall under the water taking permit system as these takings predate the permit system. The location of municipal intakes and outfalls are shown on Figure 33 and tabulated on Table 15.

7.2.2. Rural

The majority of rural domestic water is obtained from a combination of wells, cisterns and/or purchases of imported water. Domestic well use is limited in areas underlain by poor quality ground water such as the southern part of the study area which is underlain

MUNICIPALITY	WATER SOURCE	WATER TREATMENT CAPACITY x1000 m^3	POPULATION SERVED
FORT ERIE	LAKE ERIE	50.006	21,506
NIAGARA FALLS	NIAGARA RIVER	145.472	68,843
NIAGARA-ON-THE-LAKE VIRGIL/ST. DAVIDS	ST. CATHARINES DECEW WATER SUPPLY SYSTEM AND GROUND WATER (STAND BY)	9.492	10,029
PELHAM (FONTHILL) FONTHILL WELL SUPPLY	GROUND WATER AND WELLAND WATER SUPPLY SYSTEM	4.546	2,814
PORT COLBORNE	WELLAND SHIP CANAL	27.276	15,597
ST. CATHARINES / THOROLD (DECEW)	WELLAND SHIP CANAL	190.932	149,520
THOROLD (PORT ROBINSON)	WELLAND SHIP CANAL	0.700	377
WELLAND	WELLAND SHIP CANAL	86.374	49,697

NOTES : * from MOE Ontario Water Treatment Plant Listing, December 1986.

Table 14 - Municipal Water Supply*

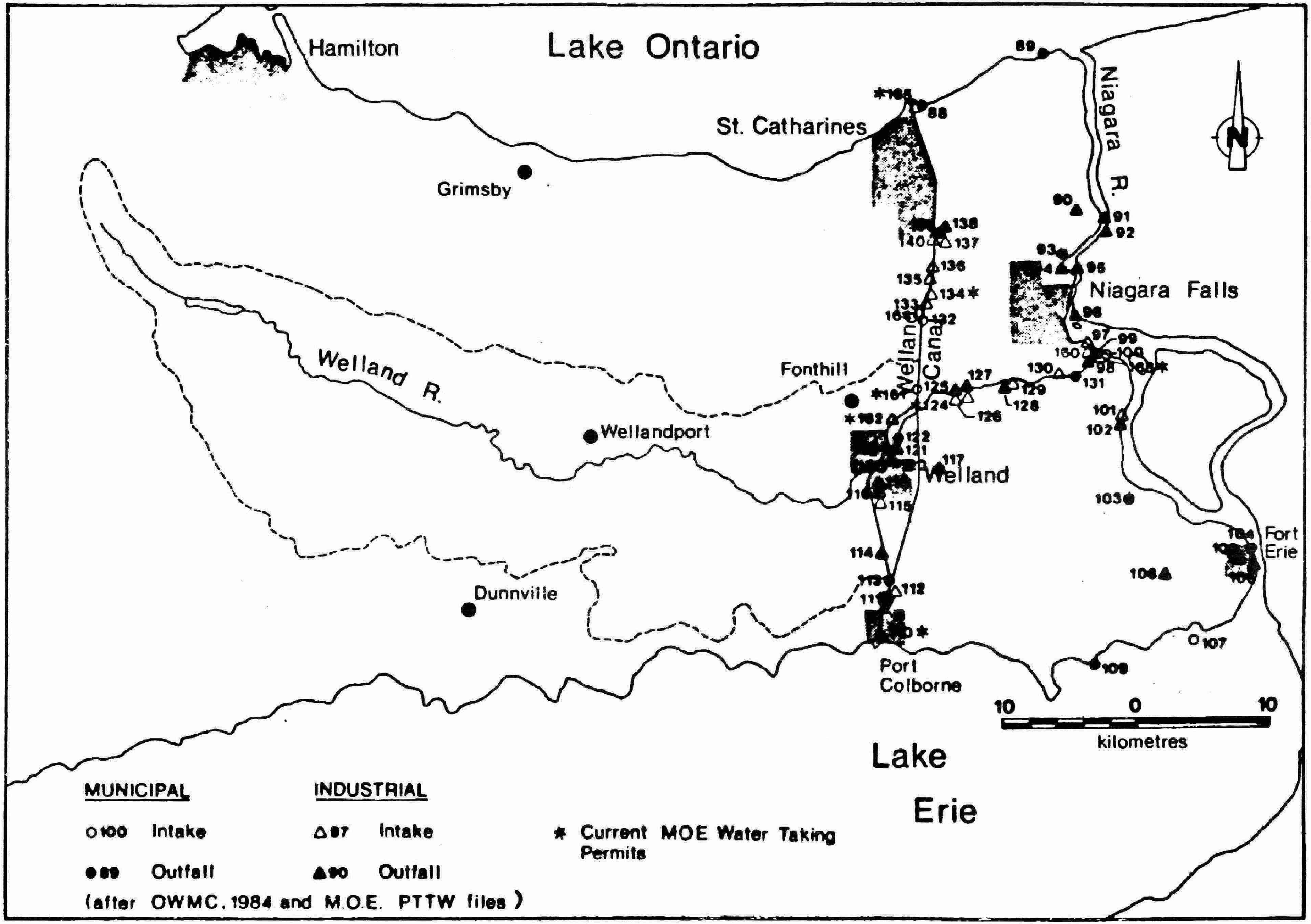


Figure 33 - Location of Industrial and Municipal Surface Water Intakes and Outfalls

by the Salina Formation. In such areas, there is generally a heavier reliance upon cisterns, imported water, or alternate surface water sources.

Private homes or cottages adjacent to major surface water bodies such as Lake Ontario, Lake Erie, and the upper Niagara River often obtain domestic water supplies from these sources. More limited use is made of the Lower Welland River for rural domestic use due to water quality consideration.

7.2.3 Industry

There are 17 existing permits for industrial water takings with a combined permitted water taking of 1.6 m^3/s from both surface water and ground water sources. One of these permits includes both surface and ground water use. Unless otherwise stated in the permit, combined surface water and ground water permits are assumed to have equal quantities of surface water and ground water. Quarry dewatering operations are listed in the Ontario Ministry of the Environment's surface water files since most of these occur from open excavations. For consistency these are listed with other surface water sources in the following discussions. Although it is recognized that the source of this water is essentially ground water.

There are 11 existing surface water permits for 1.4 m^3/s. An inventory of both industrial and municipal surface water intakes and outfalls was completed for the OWMC (1984). These are shown on Figure 33 and tabulated on Table 15. There are 19 industrial intakes from surface water source. Six of these have existing Ontario Ministry of the Environment permits and a number of others are in the process of being renewed. The current status of all the industrial intakes was not established for this study although a number of intakes are thought to be inactive or used intermittently.

There are seven permits for industrial use from ground water for a total of 0.15 m^3/s. Relatively large amounts of water are required by industries and only limited areas are capable of producing high capacity wells with acceptable water quality. Therefore, the development of ground water for industrial use is somewhat restricted with the greatest potential in the northern part of the study area which is underlain by the Guelph and Lockport Formations or the granular deposits of the St. Davids Gorge.

NUMBER	NAME	LOCATION
88	Port Weller STP Outfall	Welland Canal
89	Niagara-on-the-Lake STP Outfall	Lake Ontario
90	Queenston Quarries Outfall	Four Mile Creek
91	Sir Adam Beck G.S. Outfall	Niagara River
92	Sir Adam Beck G.S. Outfall	Niagara River
93	City of Niagara Falls, Stamford STP	Chippawa Power Canal
94	Cyanamid Outfall	Chippawa Power Canal
95	Cyanamid Outfall	Niagara River
96	Parks Commission Hydro Outfall	Niagara Falls
97	Parks Commission Hydro Intakes (2)	Niagara Falls
98	SOHIO Outfall	Chippawa Creek
99	Northern Electric Outfall	Chippawa Creek
100	City of Niagara Falls WTP Intake	Chippawa Creek (Kings Park)
101	Holiday Farms Intake	Niagara River
102	Holiday Farms Outfall	Niagara River
103	Stephensville-Douglastown STP Outfall (New)	Niagara River
104	Fort Erie (Angar Rd.) STP Outfall	Niagara River
105	Gould Batteries Outfall	Niagara River
106	Canadian Oxy. Chemicals Outfall	Frenchman's Creek
107	Fort Erie (Rosehill) WTP Intake	Bertie Beach, Lake Erie
108	Fleet Manufacturing Outfalls	Frenchman's Creek
109	Fort Erie (Crystal Beach) STP Outfall	Crystal Beach, Lake Erie
110	City of Port Colborne WTP Intake	Welland Canal
111	City of Port Colborne STP Outfall	Welland Canal
112	INCO Intake	Welland Canal
113	City of Port Colborne STP Outfall	Welland Canal
114	Canada Starch Cooling Water Outfall	Welland Canal
115	Algomo Steel Intake	Welland Canal
116	Union Carbide Outfall	Welland Canal
117	Stelco-Welland Tube Outfall	Lyons Creek
118	Stelco-Page Hersey Outfall	Welland Canal
119	City of Welland WTP Intake	Welland Canal
120	Wabasso Outfall	Welland Canal
121	Atlas Steels Outfall	Welland River
122	City of Welland STP Outfall	Welland River
123	McMaster Avenue Combined Sewer	Welland River
124	B.F. Goodrich Intake	Welland River
125	B.F. Goodrich Outfall	Welland River
126	Cyanamid Welland Plant Intake	Welland River
127	Cyanamid Welland Plant Outfall	Welland River
128	Ford Glass Outfall (2)	Welland River
129	Ford Glass Intake	Welland River
130	Chippawa Power Canal Intake	Welland River
131	Stanley Avenue CS (separated)	Chippawa Creek
132	City of St. Catharines (Decew Falls) WTP Intake	Welland Canal
133	Beaverwood Fibre Intake	Welland Canal
134	Ontario Paper Intake	Welland Canal
135	Thorold P.U.C. Intake	Welland Canal
136	General Motors Intake	Welland Canal
137	General Motors Intake	Welland Canal
138	General Motors Outfall (Foundry)	Welland Canal
139	General Motors Outfall (Cooling)	Welland Canal
140	Kimberley-Clarke-Domtar Intake	Welland Canal
160	Sir Adam Beck Diversion Tunnel Inlets (2)	Niagara River
161	Thorold (Port Robinson) WTP Intake	Welland Canal
162	Fox Holdings Ltd Intake	Welland Canal
163	Norton Company Intake	Chippawa Creek
164	Exolon-Esk Intake	Welland Canal
165	Potter Distilleries Intake	Welland Canal

NOTE : * modified from OWMC 1984

Table 15 - List of Industrial and Municipal Surface Water Intakes and Outfalls*

7.2.4 Agriculture

There are 42 existing permits for agricultural use of water within the Phase I study area with a total use of 0.20 m^3/s. This includes five permits with both surface water and ground water use.

Most of the permitted surface water sources for agricultural use occur in the area north of the Niagara Escarpment. The majority of these are used for irrigation. Permitted ground water withdrawals for agricultural use is 0.0040 m^3/s. This represents about 2% of the total quantity of permitted agricultural use of 0.20 m^3/s.

Rural areas not serviced by municipal water supplies rely upon individual wells, cisterns, ponds and/or streams for domestic use and stock watering. The majority of rural residential water uses represent relatively small amounts of water on an individual basis and do not require a permit to withdraw water.

7.2.5 Recreation

Recreational water use occurs mainly along the shores of Lakes Erie and Ontario and along the Niagara River. Major uses include boating, swimming, and fishing. Supervised recreational beaches as well as fish spawning and fish run areas have been identified (OWMC, 1984) and are shown in Figure 34.

The Falls at Niagara are one of the most well known scenic attractions of North America. This scenic water resource has significant impact on the development of the tourist industry in the area. Flows over the Falls are regulated so as to optimize the scenic potential of the falls during peak tourist viewing times. The Niagara River Treaty of 1950 requires that during daylight hours of the tourist season (April through October), a minimum of flow over the falls of 2830 m^3/s be maintained and 1410 m^3/s at all other times.

The old Welland Canal at Welland is no longer in use as a shipping canal. It has provided limited water based recreational opportunities for canoeing and has served in the past as a training area for rowing competitions. The lower Welland River, upstream (west) of the Chippawa Power Canal is well suited for recreational canoeing although limited opportunities exist for access.

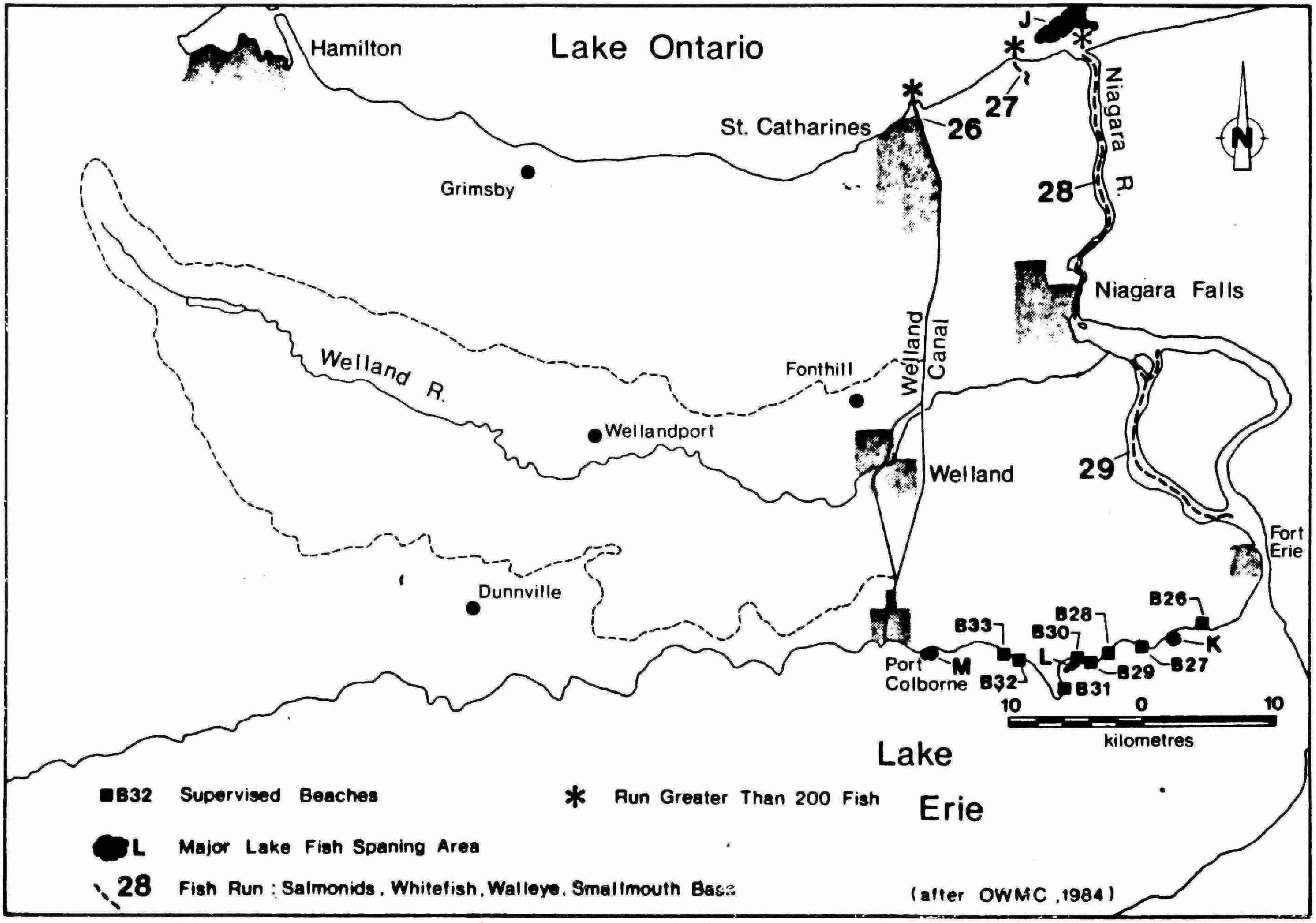


Figure 34 - Recreational Beaches, Fish Spawning And Fish Run Areas

Ontario Ministry of the Environment permitted water uses for recreational purposes are primarily for irrigation of golf courses. There are 13 existing permits for recreational use for a total usage of 0.13 m^3/s. This includes nine surface water permits, two ground water permits, and two permits with both surface and ground water sources. About 15% of the permitted recreational water use is from ground water and the remainder from surface water.

7.2.6 Other Uses

The Welland Ship Canal is a major surface water body and separates the Phase I and Phase II study areas. Its use is primarily as a major transportation route between Lake Erie and Lake Ontario for the movement of industrial and agricultural products. It is recognized as a crucial passageway allowing access to the upper Great Lakes by ocean going vessels. It also provides a source of water for municipal and industrial use as well as hydroelectric power generation. The presence of the Welland Canal has had a significant impact on the development of the eastern portion of the Niagara Peninsula.

A major use of surface water is for the generation of hydroelectric power. Water is diverted directly from the Niagara River, the Welland Ship Canal, and the Welland River for hydroelectric power generation. A sketch showing water diversions for hydroelectric power generation on both the Canadian and American sides of the Niagara River are shown schematically on Figure 35. The Canadian Hydroelectric plants include the Canadian Niagara (Rankine) Ontario Power, Toronto Power, two Sir Adam Beck plants and two Power Glen (Decew) plants. All plants except Toronto Power are currently in operation.

The Chippawa Power Canal and two underground tunnels beneath the City of Niagara Falls supply a maximum combined flow of about 1840 m^3/s for the two Sir Adam Beck generating stations. The Chippawa Power Canal has significantly altered the flow characteristics of the lower Welland River channel. A discussion of this is provided in Section 5.0 of this report. Smaller diversions from the Niagara River of 280 m^3/s and 238 m^3/s supply the Canadian Niagara and Ontario Power Generating Stations, respectively. These are older generating stations. The former is located immediately above the Horseshoe Falls and the latter is immediately below the Falls.

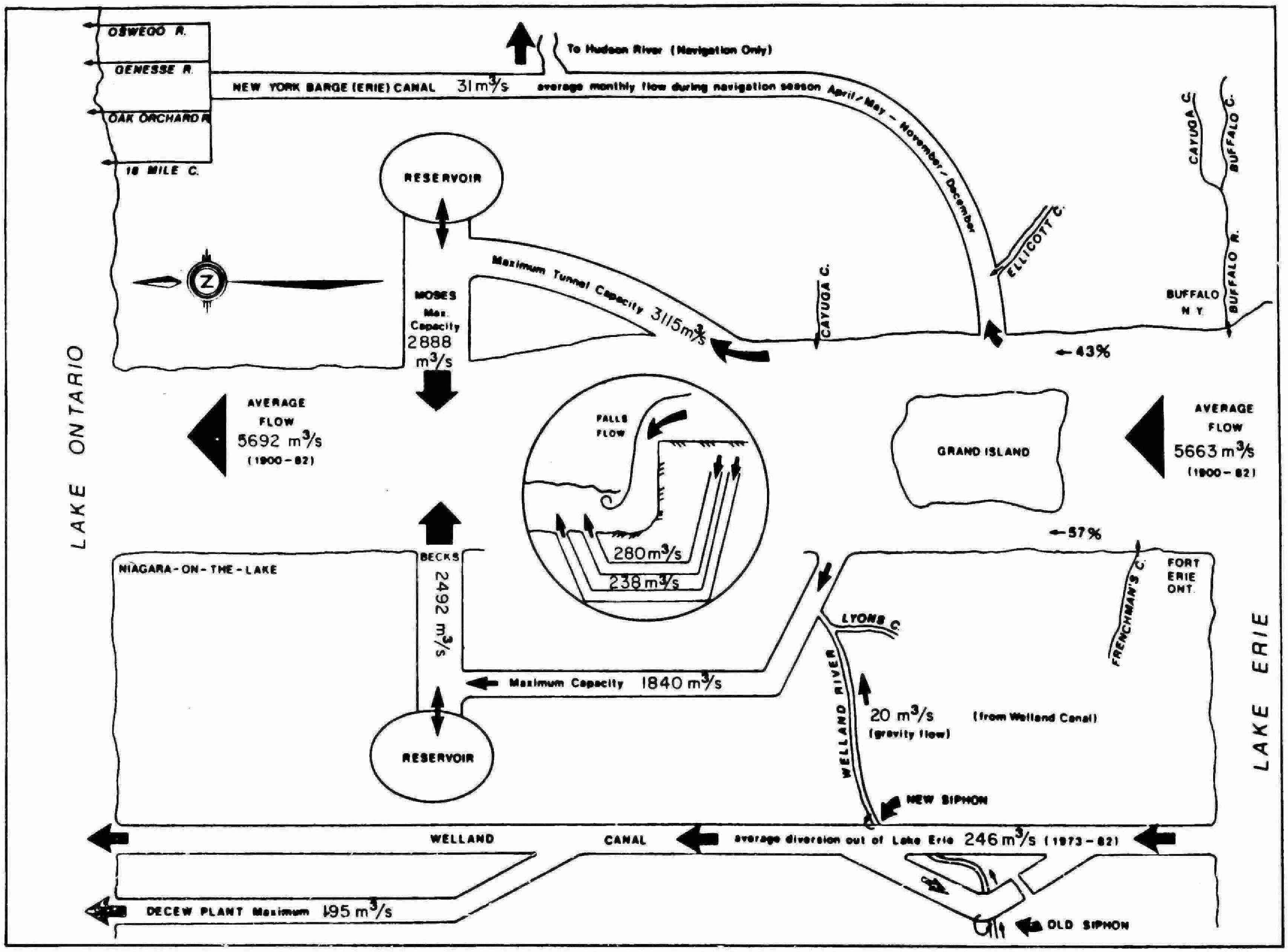

OSWEGO R.
GENESSE R.
OAK ORCHARD R.
18 MILE C.
NEW YORK BARGE (ERIE) CANAL 31 m³/s average monthly flow during navigation season April/May - November/December
To Hudson River (Navigation Only)
RESERVOIR
Maximum Tunnel Capacity 3115 m³/s
MOSES Max. Capacity 2888 m³/s
CAYUGA C.
ELLICOTT C.
CAYUGA C.
BUFFALO C.
BUFFALO R.
BUFFALO N.Y.
43%
LAKE ONTARIO
AVERAGE FLOW 5692 m³/s (1900-82)
FALLS FLOW
280 m³/s
238 m³/s
GRAND ISLAND
AVERAGE FLOW 5663 m³/s (1900-82)
57%
NIAGARA-ON-THE-LAKE
BECKS 2492 m³/s
Maximum Capacity 1840 m³/s
RESERVOIR
LYONS C.
WELLAND RIVER
20 m³/s (gravity flow)
(from Welland Canal)
FRENCHMAN'S C.
FORT ERIE ONT.
LAKE ERIE
NEW SIPHON
WELLAND CANAL
average diversion out of Lake Erie 246 m³/s (1973-82)
DECEW PLANT Maximum 195 m³/s
OLD SIPHON

Figure 35 - Schematic Diagram Showing Flows and Hydro-Electric Capacities of the Niagara River, Welland Canal, and New York Barge Canal

(after Report of Niagara River Toxics Committee, 1984)

A maximum diversion from the Welland Ship Canal of about 195 m^3/s supplies the two Decew generation stations at St. Catharines. The Welland Ship Canal also provides about 20 m^3/s of flow to the Welland River. This is accomplished by gravity flow through six culvert type standpipes in the bottom of the old Welland Canal at the old Welland River syphon. A major benefit of this diversion is the stimulation of flow through a semi-stagnant portion of the old Welland Canal and the lower portion of the Welland River. Smaller diversions from the new Welland Canal into the Welland River at Port Robinson and into Lyons Creek are also maintained for riparian flow. A discussion of stream flow characteristics is provided in Section 5.0.

7.3 PHASE II - WATER USE

The Phase 2 study area includes the Welland River drainage basin upstream of the Welland Ship Canal and a small area that drains into the Welland Ship Canal from the west. The major water uses in the Phase II study area include industrial, agricultural, rural residential, municipal, and recreational.

There are 21 existing water taking permits. Four of these are ground water permits, fourteen are surface water permits, and three are combined surface water and ground water permits. The total permitted water takings are 0.53 m^3/s. The largest permitted use is industrial followed by agricultural, recreational, and municipal. A summary of permitted water use is shown on Table 16.

7.3.1 Municipal

There are two existing permits to take water for municipal use. One permit is for a ground water source in Fonthill and the other is for surface water withdrawals from the Welland Ship Canal at Port Robinson. The total permitted municipal use is 0.022 m^3/s.

A permit to take water for domestic use from the Welland River near Port Davidson has recently expired. This permit is currently being renewed for a maximum withdrawal of 0.0005 m^3/s.

	Municipal	Agricultural	Industrial	Recreational	Totals
Ground Water	0.0189	0.0341	0.0005	0.0108	0.0643
Surface Water	0.0028	0.1376	0.2025	0.1236	0.4665
Totals	0.0217	0.1717	0.2030	0.1344	0.5308

NOTE : Units in cubic metres per second
* includes permitted water use only

Table 16 Water Use in the Phase II Study Area*

7.3.2 Rural

Much of the Welland River Basin west of the City of Welland consists of farm land with only a few small rural communities. The area has a relatively low population density and no estimate for the total population is available.

Rural residential water use including domestic use on farms is the most common form of water use in this area. Relatively small quantities of water are used on an individual basis therefore no permits are required by the Ontario Ministry of the Environment. Studies conducted in the Wellandport area indicate that the major sources of water for rural residential use include wells, cisterns, and to a minor extent, ponds and springs (OWMC, 1984). There appears to be an adequate supply of ground water for rural residential use throughout most of the area, although the quality of ground water varies. In areas of poorer quality ground water, such as along the southern portion of the Welland River Basin, there is a greater reliance upon cisterns as a source of water. Cisterns are generally supplied by rain water and are occasionally supplemented with imported municipal water from adjacent communities. Bottled water for drinking is used to a limited extent. Spring fed ponds and wells are a source of supply in a few cases particularly in areas near the Welland River.

7.3.3 Industry

There are three existing permits for industrial use. Two are from surface water sources and one is from a ground water source. One surface water permit is for quarry dewatering in the Port Colborne area and the other is for industrial use. The latter obtains water from the Old Welland Ship Canal north of Welland. The ground water permit is for processing cherries. The total amount of permitted industrial water use in the upper Welland River Basin is 0.20 m^3/s.

7.3.4 Agriculture

Agricultural permitted water use is primarily for irrigation. There are nine existing permits, three of these are for ground water and six are for surface water sources.

The Phase II study area is primarily rural in nature; therefore, a major portion of the unpermitted water use will be in support of the various agricultural operations throughout the area. Water use surveys have been conducted in the Wellandport area (GLAL, 1985a;

1985b; 1986a). These studies showed that major agricultural uses of ground water and surface water are livestock watering and crop spraying. Ground water in the area is a major source of supply for agricultural use, although surface water is also used where sufficient supplies are available. In a few instances, cisterns are also used for agricultural purposes.

7.3.5 Recreation

There are seven existing Ontario Ministry of the Environment permits for recreational water use. All permits, except one, are for surface water sources. Surface water permits include two permits for golf course irrigation, three permits for recreational ponds, one of which is also used for irrigation, and one permit for the Binbrook Reservoir. The only ground water permit is combined with surface water for golf course irrigation. The total permitted recreational water use is 0.13 m^3/s. The Binbrook reservoir lies within the Binbrook Conservation Area and provides water based recreational opportunities. The Chippawa Conservation Area west of Wellandport also provides recreational access to the Welland River. The Welland River provides recreational canoeing and limited power boating opportunities in its wider reaches, primarily downstream of the Chippawa Conservation Area. These opportunities have become restricted in recent years due to reported buildup of aquatic plants in certain areas.

8.0 FINDINGS

As the population in any area increases, the conservation and proper management of surface and ground waters in terms of quantity and quality becomes increasingly important. Furthermore the expansion of industry and agriculture also makes significant demands on the water resources. In the Niagara area the principal concerns are with respect to naturally occurring, poor water quality in both ground and surface waters. Water quantity is of lesser importance.

Because of insufficient data some assumptions were made regarding the interpretation of inventory information. The following discussions identify where additional information is required to validate the assumptions and where the more significant water management problems are in the study area.

8.1 DATA NEEDS

A significant amount of data on the water resources in the area were available; however, there are areas of insufficient coverage which are listed below:

8.1.1 Surface Water Needs

Only limited information is available on toxic organic parameters. Upgrading of water quality parameters at selected stations is required to address industrial impacts similar to the studies being done for the Niagara River Toxics Management Plan. Synoptic surveys, upstream and downstream of the major outfalls, should be initially conducted to identify optimal sampling sites.

Additional data are required in the upper reaches of the Welland River to confirm the source(s) of poor quality water as well as at the Port Robinson and Montrose Bridge sites downstream of the City of Welland.

Long term predictions for surface water irrigation north of the Niagara Escarpment are difficult to provide with any degree of accuracy until more information becomes available. Detailed streamflow information is required on the small streams that flow into Lake Ontario. However, zero flows reported during the summer months indicate that these streams are not a reliable source for high demand purposes such as irrigation.

8.1.2 Ground Water Needs

Insufficient data are available on the deep ground water flow system for reliable predictions of contaminant movement at any depth below the bedrock surface. In particular, hydraulic head information for water bearing horizons below the weathered bedrock are required before reliable predictions can be presented. Figure 36 (in map pocket) is a hydrogeological cross-section along the eastern edge of the Welland Canal. Water level information from the bedrock aquifer (Figure 20 in map pocket) was superimposed on the cross-section and highlights the deficiency in data to delineate ground water movement at depth (in the bedrock aquitard). Figure 20 suggests that ground water movement in the overlying bedrock aquifer is westward towards the Welland Canal in the immediate vicinity of the cross-section.

Insufficient data and studies are available on infiltration rates and mechanisms for ground water movement through the overburden materials to the bedrock aquifer. Studies to date suggest that diffusion processes are important in the chemical make-up of the ground waters in the overburden.

Rates of ground water movement in the fine-grained overburden materials are estimated in mm/a and ground water in the bedrock aquifer may be prehistoric in age across parts of the study area. These aging estimates need to be confirmed in other parts of the study area with additional data.

Further studies on fracture orientations, magnitude, and depth of hydraulic activity are also required to provide assurances of hydrogeological security in fractured/weathered, fine-grained overburden materials.

8.2 WATER RESOURCES MANAGEMENT PROBLEMS

The major water resources issues are related to quality problems. Quantity problems exist in isolated areas related to dewatering, irrigation, and flooding. Sufficient water still appears to be available for additional power generation in the Niagara Falls area.

8.2.1 Water Quality Problems

Poor natural quality of both the ground and surface waters is prevalent in the area. The ground water quality is directly related to slow ground water movement which permits significant chemical dissolution of the materials in which the ground water circulates to proceed. Baseflow contributions of ground water to streamflow contribute to poor quality of these streams.

Other water quality problems are related to man-made contamination and waste assimilation by the natural ground and surface waters. Problems from landfills, septic systems, or contaminant spills are generally localized but can become persistent in ground water as a continuing source of contamination. Furthermore, fine-grained materials are generally widespread through the area and present problems with respect to waste assimilation by dilution. For example, private waste disposal systems have operational difficulties in areas with low permeability materials such as silt or clay, or in areas of shallow bedrock, where suitable tile-bed soils must be imported. However, these same fine-grained materials do provide containment for accidental spills or landfill leachate migration as well as attenuation capacity by sorption processes.

Waste assimilation of sewage treatment plant waste water effluents by surface waters is a common occurrence in the eastern part of the study area. However, limited dilution capability is available in the summer because of low flows. Furthermore, recent problems with low quantities of highly toxic substances has caused concerns that are being addressed by special committees such as the Niagara River Toxics Management Committee and programs such as Municipal Industrial Strategy for Abatement (MISA).

8.2.2 Water Quantity Problems

The hydrologic budget estimates indicate that total recharge to the major aquifer (the bedrock aquifer) underlying the study area is about 4 m^3/s. This value is significantly larger than the 0.3 m^3/s of ground water takings on file with the Ontario Ministry of the Environment. Domestic water withdrawals from water wells are estimated at about 0.3 m^3/s, assuming a rural population of 50 000 and a usage of about 500 litres per day per person. Thus, there appears to be sufficient ground water for continued development in the area.

Water takings for agricultural purposes (irrigation and livestock watering mainly) totals about 0.4 m^3/s. Almost 75% or 0.3 m^3/s is from surface water sources. This creates difficulties in areas serviced by small streams because of low or zero flows occurring during the summer months when agricultural demands are greatest.

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APPENDIX A : GENERAL WATER QUALITY DATA 1982 - 1986
STATION 11-1-3
WELLAND RIVER AT MONTROSE BRIDGE

PARAMETER	UNITS	MEAN	MAXIMUM	MINIMUM	NUMBER OF SAMPLES
Alkalinity	mg/L	94	124	47	157
Chloride	mg/L	19.9	27.6	14.5	58
Conductivity	umhos/cm	358	634	263	143
Copper	mg/L	0.007	0.026	0.001	190
Dissolved Oxygen	mg/L	9.9	16.4	0.08	114
Fecal Coliforms (1)	counts/100 mL	800	10,900	50	54
Fecal Streptococci (1)	counts/100 mL	146	4,500	12	54
Field pH	---	7.90	8.80	6.85	111
Total Ammonia (2)	mg/L	2.064	12.4	0.074	37
Nitrate & Nitrite (2)	mg/L	2.132	12.6	0.225	101
Total Kjeldahl N (2)	mg/L	4.264	19.5	0.31	36
Lead	mg/L	0.006	0.025	0.002	61
Phenols	ug/L	1.0	2.8	0.0	56
Total Phosphorus	mg/L	0.154	0.815	0.016	248
Suspended Solids	mg/L	32.2	451.7	2.2	251
Zinc	mg/L	0.016	0.061	0.004	113

NOTES :

1. Geometric means.
2. Data are for period 1984 to 1986.

APPENDIX A : GENERAL WATER QUALITY DATA 1982 - 1986
STATION 11-1-5
WELLAND RIVER, NEW SYPHON AT PORT ROBINSON

PARAMETER	UNITS	MEAN	MAXIMUM	MINIMUM	NUMBER OF SAMPLES
Alkalinity	mg/L	99	114	63	56
Chloride	mg/L	19.9	31.0	13.4	56
Conductivity	umhos/cm	338	520	270	57
Copper	mg/L	0.005	0.016	0.002	53
Dissolved Oxygen	mg/L	9.43	13.2	5.4	57
Fecal Coliforms (1)	counts/100 mL	2,240	23000	650	35
Fecal Streptococci (1)	counts/100 mL	340	3700	20	35
Field pH	---	7.89	8.40	6.85	54
Total Ammonia (2)	mg/L	0.211	0.470	0.054	32
Nitrate & Nitrite (2)	mg/L	0.864	3.470	0.230	32
Total Kjeldahl N (2)	mg/L	0.847	2.500	0.240	32
Lead	mg/L	0.006	0.011	0.004	20
Phenols	ug/L	1.0	3.4	0.0	54
Total Phosphorus	mg/L	0.120	0.710	0.029	55
Suspended Solids	mg/L	30.1	432.9	2.5	55
Zinc	mg/L	0.014	0.110	0.003	54

NOTES :

1. Geometric means.
2. Data are for period 1984 to 1986.

APPENDIX A : GENERAL WATER QUALITY DATA 1982 - 1986
STATION 11-1-7
WELLAND RIVER AT BRIDGE SOUTH OF WELLAND AIRPORT

PARAMETER	UNITS	MEAN	MAXIMUM	MINIMUM	NUMBER OF SAMPLES
Alkalinity	mg/L	105	146	59	44
Chloride	mg/L	27.0	85.3	13.0	55
Conductivity	umhos/cm	460	807	243	31
Copper	mg/L	0.005	0.006	0.005	2
Dissolved Oxygen	mg/L	8.1	13.2	1.8	57
Fecal Coliforms (1)	counts/100 mL	174	2700	20	25
Fecal Streptococci (1)	counts/100 mL	137	9700	20	25
Field pH	---	7.70	8.25	6.40	54
Total Ammonia (2)	mg/L	0.210	0.830	0.012	33
Nitrate & Nitrite (2)	mg/L	1.508	4.420	0.015	33
Total Kjeldahl N (2)	mg/L	1.510	3.000	0.590	32
Lead	mg/L	0.004	0.004	0.004	1
Phenols	ug/L	0.7	1.2	0.2	2
Total Phosphorus	mg/L	0.241	0.810	0.010	53
Suspended Solids	mg/L	45.9	406.9	0.9	55
Zinc	mg/L	0.022	0.031	0.014	2

NOTES :

1. Geometric means.
2. Data are for period 1984 to 1986.

APPENDIX A : GENERAL WATER QUALITY DATA 1982 - 1986
STATION 11-1-8
WELLAND RIVER AT SINCLAIRVILLE BRIDGE

PARAMETER	UNITS	MEAN	MAXIMUM	MINIMUM	NUMBER OF SAMPLES
Alkalinity	mg/L	128	244	52	35
Chloride	mg/L	47.5	132.8	8.3	54
Conductivity	umhos/cm	675	1580	289	55
Copper	mg/L	0.009	0.025	0.001	53
Dissolved Oxygen	mg/L	8.7	11.8	5.0	56
Fecal Coliforms (1)	counts/100 mL	217	9300	20	34
Fecal Streptococci (1)	counts/100 mL	307	7400	20	33
Field pH	---	7.73	8.30	6.50	54
Total Ammonia (2)	mg/L	0.112	0.564	0.014	33
Nitrate & Nitrite (2)	mg/L	1.367	10.300	0.015	33
Total Kjeldahl N (2)	mg/L	1.038	2.700	0.540	33
Lead	mg/L	0.009	0.043	0.003	28
Phenols	ug/L	0.6	4.2	0.0	55
Total Phosphorus	mg/L	0.188	0.930	0.013	55
Suspended Solids	mg/L	90.4	542.4	5.4	53
Zinc	mg/L	0.015	0.064	0.004	53

NOTES :

1. Geometric means.
2. Data are for period 1984 to 1986.

APPENDIX A : GENERAL WATER QUALITY DATA 1982 - 1986
STATION 11-1-9
WELLAND RIVER, LOT 25, CONC. 7, FORMER TOWNSHIP OF BINBROOK

PARAMETER	UNITS	MEAN	MAXIMUM	MINIMUM	NUMBER OF SAMPLES
Alkalinity	mg/L	136	230	71	55
Chloride	mg/L	42.9	181.0	8.3	55
Conductivity	umhos/cm	581	1590	353	55
Copper	mg/L	0.007	0.026	0.001	53
Dissolved Oxygen	mg/L	8.5	14.0	4.3	55
Fecal Coliforms (1)	counts/100 mL	128	12,000	10	34
Fecal Streptococci (1)	counts/100 mL	177	6,900	10	34
Field pH	---	7.66	8.20	6.55	54
Total Ammonia (2)	mg/L	0.156	0.718	0.002	32
Nitrate & Nitrite (2)	mg/L	1.266	5.320	0.045	32
Total Kjeldahl N (2)	mg/L	0.901	1.770	0.420	32
Lead	mg/L	0.008	0.067	0.003	29
Phenols	ug/L	1.0	7.0	0.0	56
Total Phosphorus	mg/L	0.157	0.940	0.029	54
Suspended Solids	mg/L	59.8	466.0	7.2	54
Zinc	mg/L	0.087	4.000	0.003	53

NOTES :

1. Geometric means.
2. Data are for period 1984 to 1986.

APPENDIX A : GENERAL WATER QUALITY DATA 1982 - 1986
STATION 11-1-10
CHIPPAWA POWER CANAL, HYDRO FOOTBRIDGE

PARAMETER	UNITS	MEAN	MAXIMUM	MINIMUM	NUMBER OF SAMPLES
Alkalinity	mg/L	98	103	89	42
Chloride	mg/L	16.3	18.0	15.0	42
Conductivity	umhos/cm	294	374	272	42
Copper	mg/L	0.004	0.009	0.001	41
Dissolved Oxygen	mg/L	9.7	12.7	6.4	41
Fecal Coliforms (1)	counts/100 mL	950	4200	300	21
Fecal Streptococci (1)	counts/100 mL	276	3400	20	21
Field pH	---	8.21	8.70	7.85	39
Total Ammonia (2)	mg/L	0.146	1.480	0.020	32
Nitrate & Nitrite (2)	mg/L	0.411	1.500	0.165	32
Total Kjeldahl N (2)	mg/L	0.509	1.850	0.240	32
Lead	mg/L	0.006	0.016	0.003	10
Phenols	ug/L	0.4	3.4	0.0	41
Total Phosphorus	mg/L	0.035	0.155	0.028	42
Suspended Solids	mg/L	12.5	71.7	1.8	41
Zinc	mg/L	0.006	0.016	0.001	2

NOTES :

1. Geometric means.
2. Data are for period 1984 to 1986.

APPENDIX A : GENERAL WATER QUALITY DATA 1982 - 1986
STATION 6-14-1
WELLAND SHIP CANAL AT WEIR DOWNSTREAM FROM LAKESHORE ROAD

PARAMETER	UNITS	MEAN	MAXIMUM	MINIMUM	NUMBER OF SAMPLES
Alkalinity	mg/L	103	215	89.6	55
Chloride	mg/L	20.4	41.5	14.8	55
Conductivity	umhos/cm	321	468	274	54
Copper	mg/L	0.005	0.024	0.001	54
Dissolved Oxygen	mg/L	10.8	18.0	6.5	107
Fecal Coliforms (1)	counts/100 mL	30	430	10	59
Fecal Streptococci (1)	counts/100 mL	19	860	4	59
Field pH	---	8.09	8.70	6.90	103
Total Ammonia (2)	mg/L	0.062	0.190	0.014	34
Nitrate & Nitrite (2)	mg/L	0.404	2.130	0.150	34
Total Kjeldahl N (2)	mg/L	0.351	0.590	0.180	34
Lead	mg/L	0.009	0.060	0.003	44
Phenols	ug/L	4.0	68.0	0.0	54
Total Phosphorus	mg/L	0.044	0.170	0.015	109
Suspended Solids	mg/L	22.4	207.0	1.6	109
Zinc	mg/L	0.013	0.086	0.001	107

NOTES :

1. Geometric means.
2. Data are for period 1984 to 1986.

APPENDIX A : GENERAL WATER QUALITY DATA 1982 - 1986
STATION 6-14-2
WELLAND SHIP CANAL DOWNSTREAM FROM LAKE ERIE

PARAMETER	UNITS	MEAN	MAXIMUM	MINIMUM	NUMBER OF SAMPLES
Alkalinity	mg/L	100	107	84.2	50
Chloride	mg/L	16.7	37.0	14.1	51
Conductivity	umhos/cm	297	445	269	50
Copper	mg/L	0.003	0.010	0.001	48
Dissolved Oxygen	mg/L	10.2	14.6	6.3	50
Fecal Coliforms (1)	counts/100 mL	14	200	4	34
Fecal Streptococci (1)	counts/100 mL	14	280	4	34
Field pH	---	8.17	8.70	7.00	49
Total Ammonia (2)	mg/L	0.021	0.046	0.002	29
Nitrate & Nitrite (2)	mg/L	0.267	0.465	0.130	29
Total Kjeldahl N (2)	mg/L	0.274	0.450	0.190	29
Lead	mg/L	0.005	0.008	0.003	13
Phenols	ug/L	1.0	2.8	0.0	49
Total Phosphorus	mg/L	0.027	0.235	0.007	49
Suspended Solids	mg/L	8.3	44.2	0.7	49
Zinc	mg/L	0.004	0.021	0.001	45

NOTES :

1. Geometric means.
2. Data are for period 1984 to 1986.

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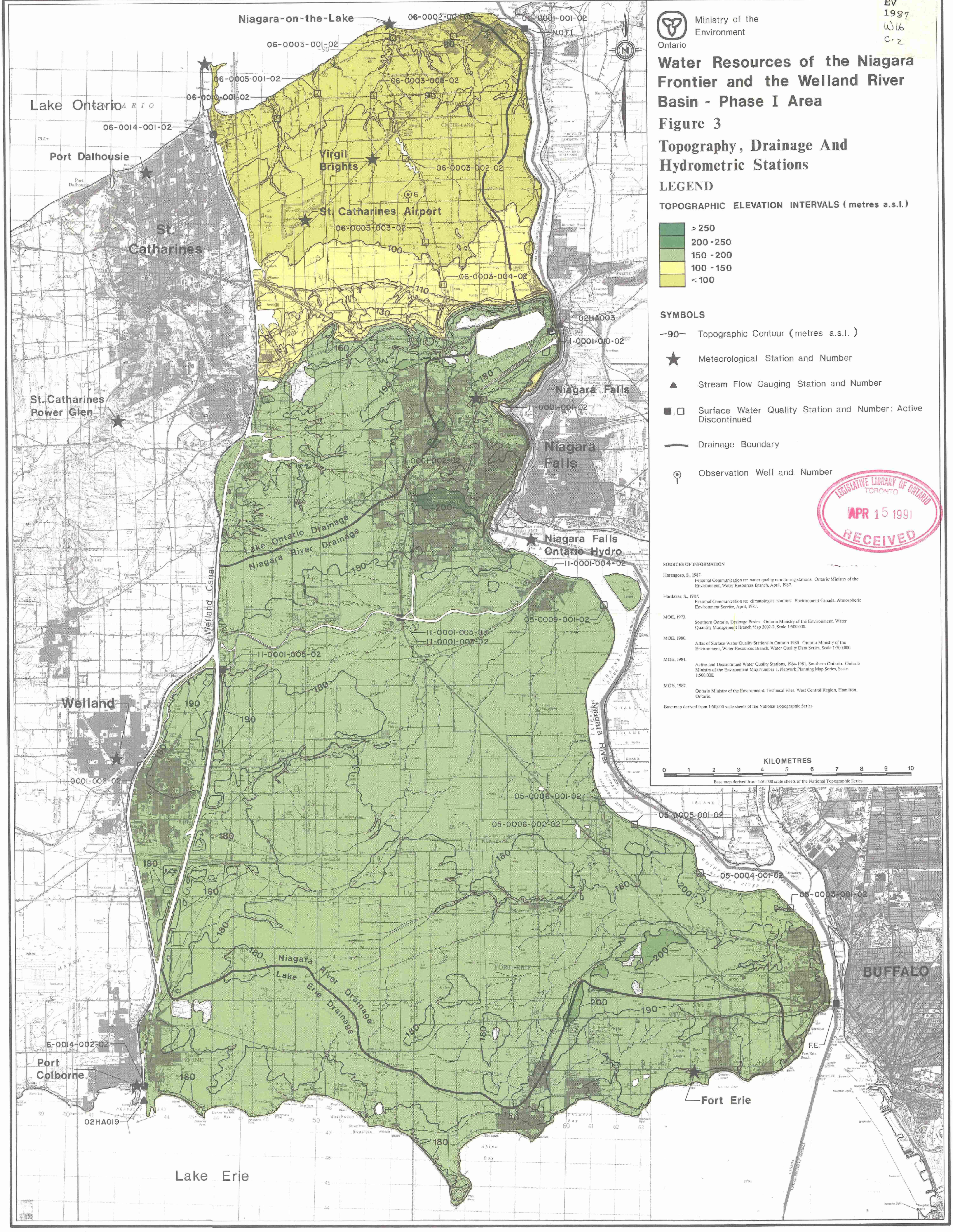

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Water Resources of the Niagara Frontier and the Welland River Basin - Phase I Area

Figure 3

Topography, Drainage And Hydrometric Stations

LEGEND

TOPOGRAPHIC ELEVATION INTERVALS (metres a.s.l.)

🟩 > 250
🟩 200 - 250
🟩 150 - 200
🟨 100 - 150
🟨 < 100

SYMBOLS

—90—	Topographic Contour (metres a.s.l.)
★	Meteorological Station and Number
▲	Stream Flow Gauging Station and Number
■, ☐	Surface Water Quality Station and Number; Active Discontinued
—	Drainage Boundary
⊙	Observation Well and Number

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SOURCES OF INFORMATION

Harangozo, S., 1987.
Personal Communication re: water quality monitoring stations. Ontario Ministry of the Environment, Water Resources Branch, April, 1987.

Hardaker, S., 1987.
Personal Communication re: climatological stations. Environment Canada, Atmospheric Environment Service, April, 1987.

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MOE, 1981.
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MOE, 1987.
Ontario Ministry of the Environment, Technical Files, West Central Region, Hamilton, Ontario.

Base map derived from 1:50,000 scale sheets of the National Topographic Series.

KILOMETRES
0 1 2 3 4 5 6 7 8 9 10

Base map derived from 1:50,000 scale sheets of the National Topographic Series.

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Water Resources of the Niagara Frontier and the Welland River Basin - Phase II Area

Ministry of the Environment
Ontario

Figure 4

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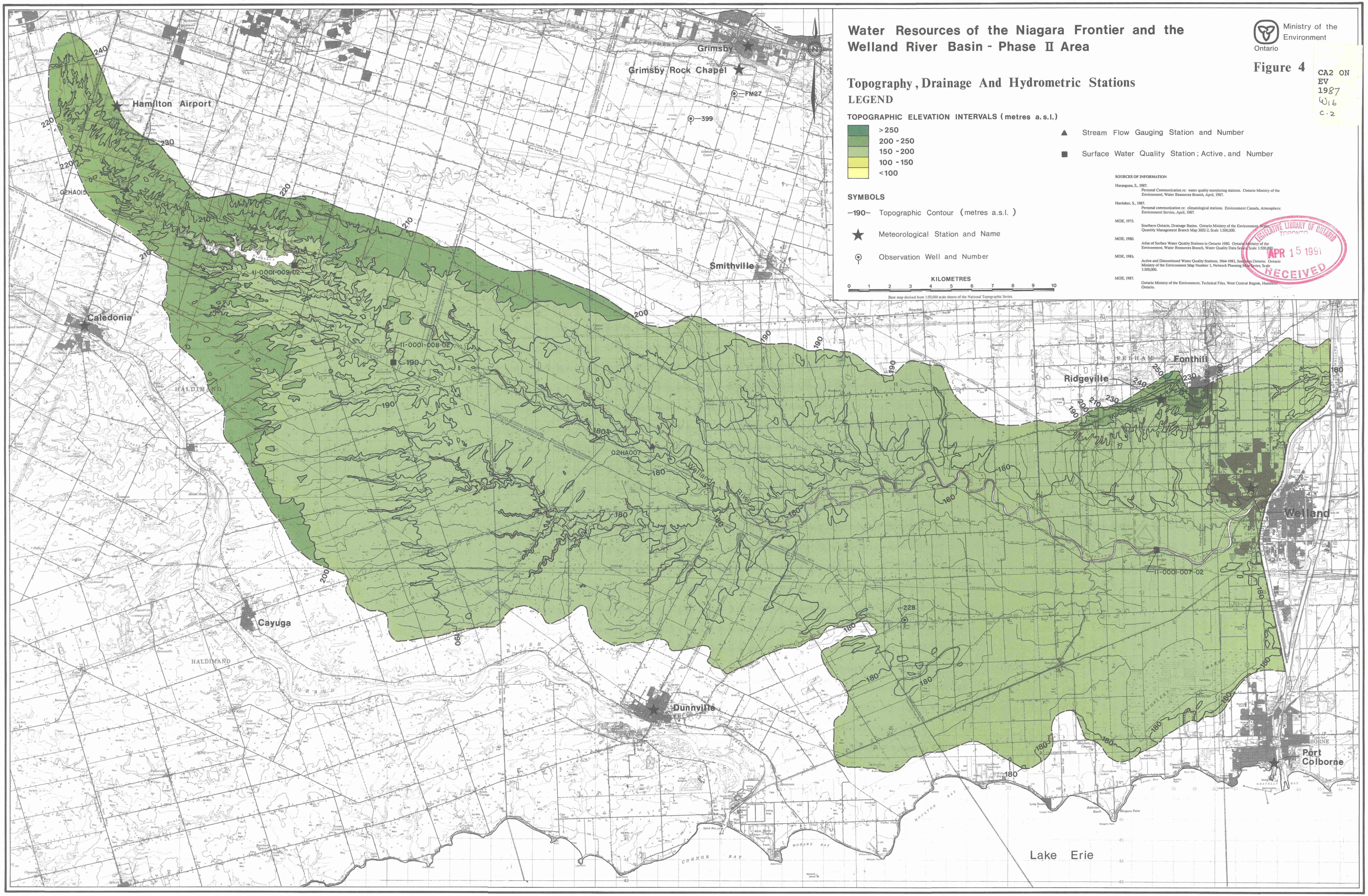
Topography, Drainage And Hydrometric Stations



LEGEND

TOPOGRAPHIC ELEVATION INTERVALS (metres a.s.l.)

- 🟩 >250
- 🟩 200 - 250
- 🟩 150 - 200
- 🟨 100 - 150
- 🟨 <100

SYMBOLS

- —190— Topographic Contour (metres a.s.l.)
- ★ Meteorological Station and Name
- ⊙ Observation Well and Number
- ▲ Stream Flow Gauging Station and Number
- ■ Surface Water Quality Station; Active, and Number

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0 1 2 3 4 5 6 7 8 9 10

Base map derived from 1:50,000 scale sheets of the National Topographic Series.

SOURCES OF INFORMATION

Harangozo, S., 1987.
Personal Communication re: water quality monitoring stations. Ontario Ministry of the Environment, Water Resources Branch, April, 1987.

Hardaker, S., 1987.
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Southern Ontario, Drainage Basins. Ontario Ministry of the Environment, Water Quantity Management Branch Map 3002-2, Scale 1:500,000.

MOE, 1980.
Atlas of Surface Water Quality Stations in Ontario 1980. Ontario Ministry of the Environment, Water Resources Branch, Water Quality Data Series, Scale 1:500,000.

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MOE, 1987.
Ontario Ministry of the Environment, Technical Files, West Central Region, Hamilton, Ontario.

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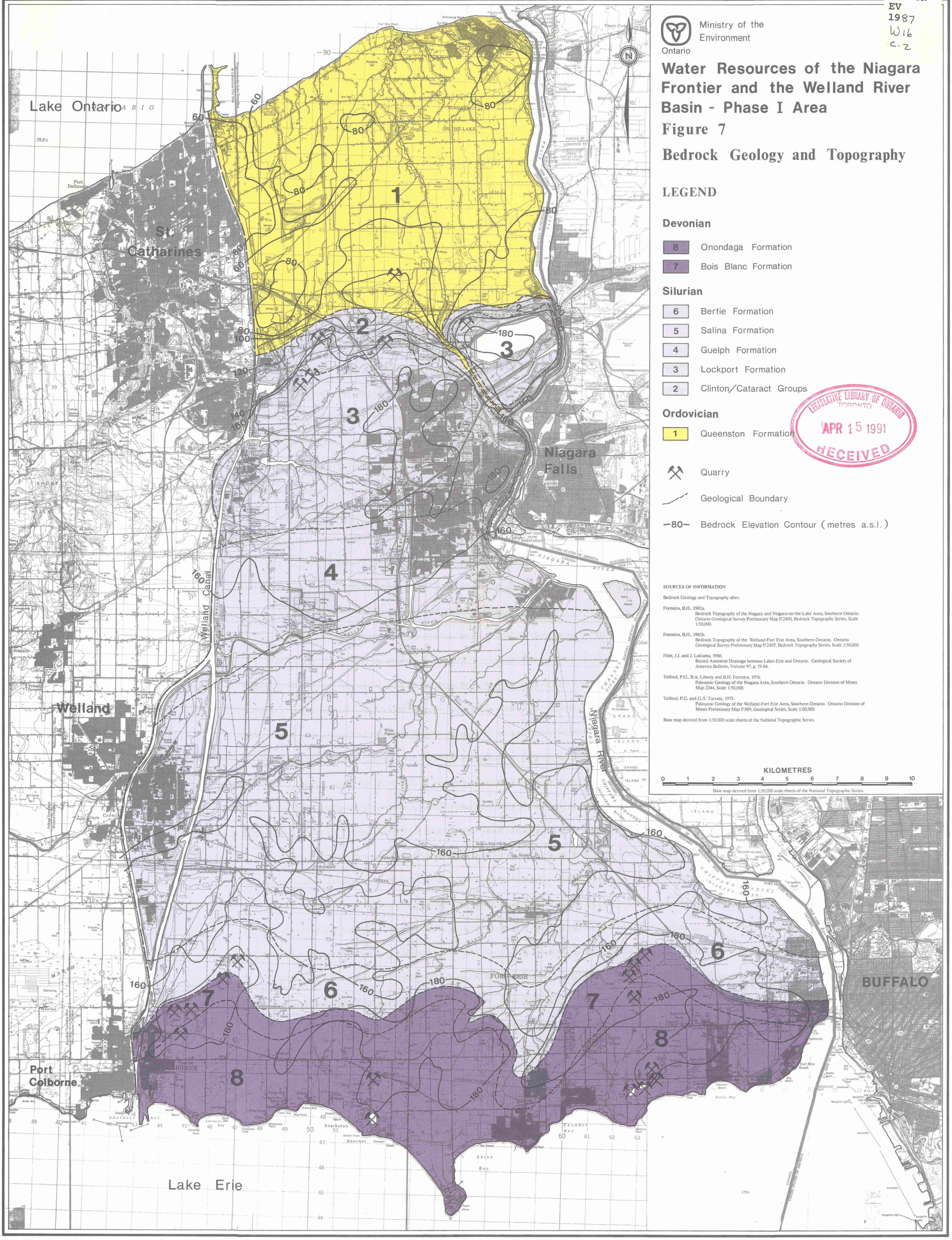

Ministry of the Environment
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Water Resources of the Niagara Frontier and the Welland River Basin - Phase I Area

Figure 7

Bedrock Geology and Topography

LEGEND

Devonian

8	Onondaga Formation
7	Bois Blanc Formation

Silurian

6	Bertie Formation
5	Salina Formation
4	Guelph Formation
3	Lockport Formation
2	Clinton/Cataract Groups

Ordovician

1	Queenston Formation

⚒ Quarry

--- Geological Boundary

—80— Bedrock Elevation Contour (metres a.s.l.)

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SOURCES OF INFORMATION

Bedrock Geology and Topography after:

Feenstra, B.H., 1981a.
Bedrock Topography of the Niagara and Niagara-on-the-Lake Area, Southern Ontario. Ontario Geological Survey Preliminary Map P.2400, Bedrock Topography Series, Scale 1:50,000.

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Buried Ancestral Drainage between Lakes Erie and Ontario. Geological Society of America Bulletin, Volume 97, p. 75-84.

Telford, P.G., B.A. Liberty and B.H. Feenstra, 1976.
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Telford, P.G. and G.A. Tarrant, 1975.
Paleozoic Geology of the Welland-Fort Erie Area, Southern Ontario. Ontario Division of Mines Preliminary Map P.989, Geological Series, Scale 1:50,000.

Base map derived from 1:50,000 scale sheets of the National Topographic Series.

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0 1 2 3 4 5 6 7 8 9 10

Base map derived from 1:50,000 scale sheets of the National Topographic Series.

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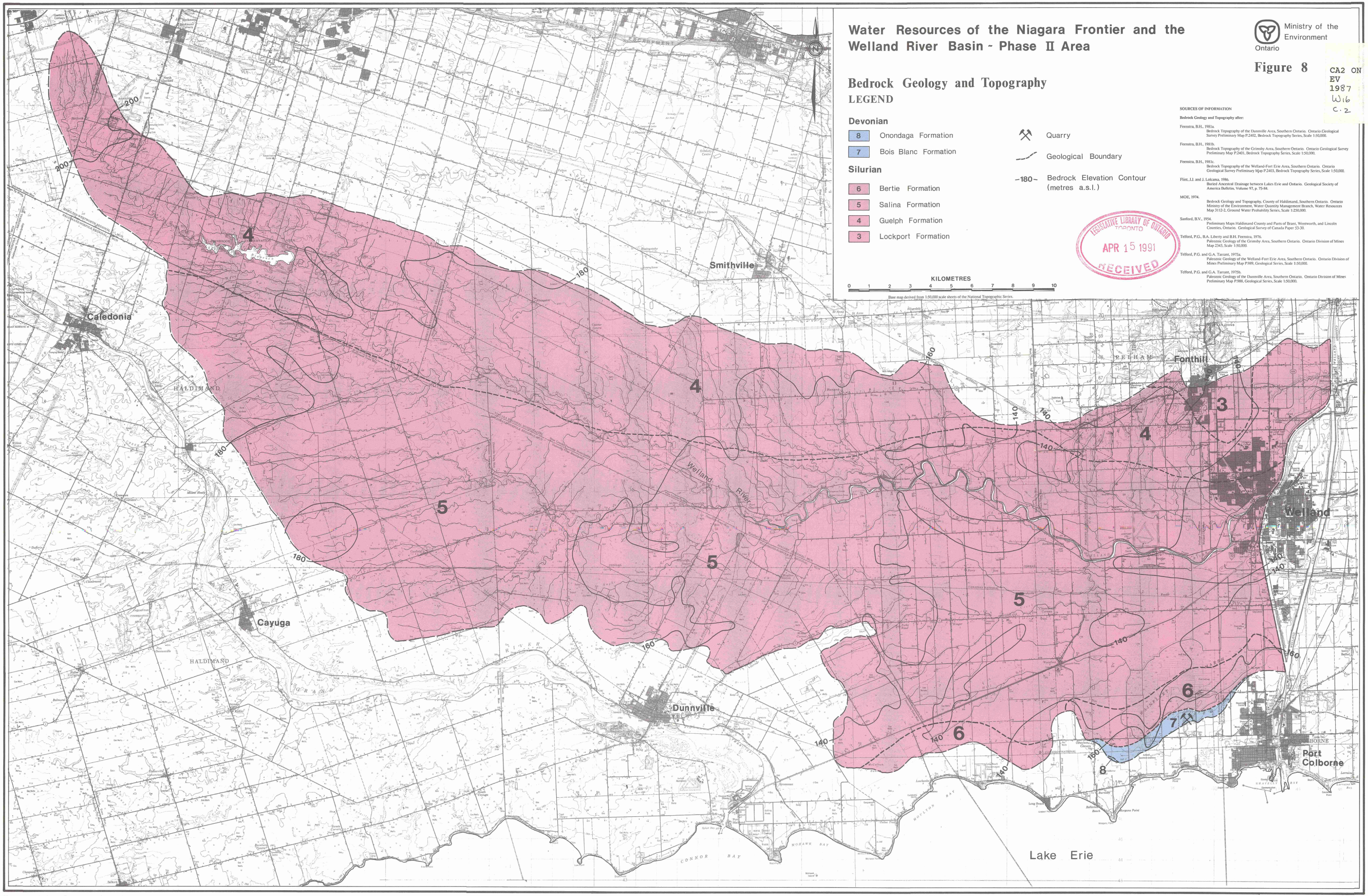

Water Resources of the Niagara Frontier and the Welland River Basin - Phase II Area

Ministry of the Environment
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Figure 8

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Bedrock Geology and Topography

LEGEND

Devonian

8	Onondaga Formation
7	Bois Blanc Formation

Silurian

6	Bertie Formation
5	Salina Formation
4	Guelph Formation
3	Lockport Formation

⚒ Quarry

--- Geological Boundary

–180– Bedrock Elevation Contour (metres a.s.l.)

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SOURCES OF INFORMATION

Bedrock Geology and Topography after:

Feenstra, B.H., 1981a.
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MOE, 1974.
Bedrock Geology and Topography, County of Haldimand, Southern Ontario. Ontario Ministry of the Environment, Water Quantity Management Branch, Water Resources Map 3112-2, Ground Water Probability Series, Scale 1:250,000.

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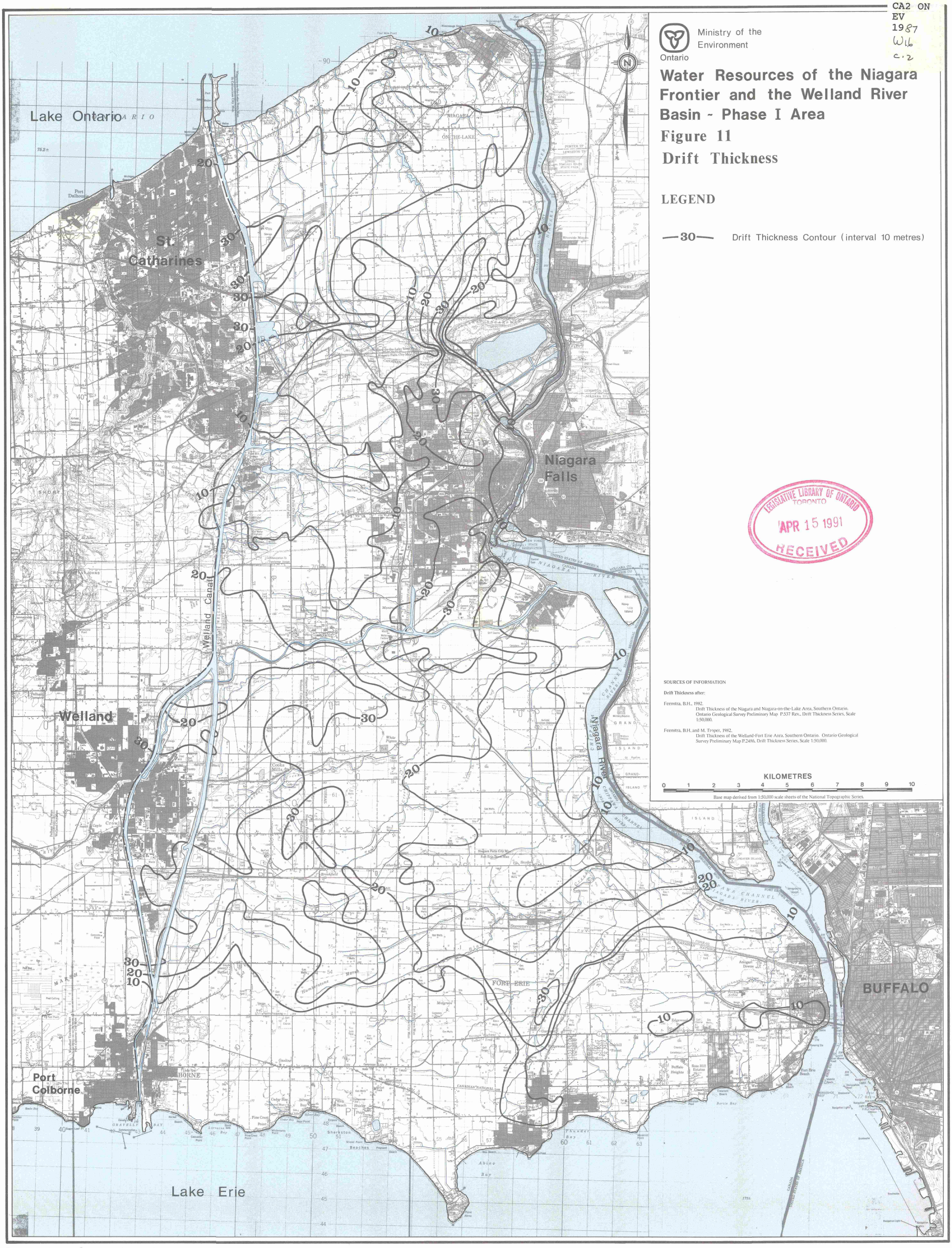
Water Resources of the Niagara Frontier and the Welland River Basin - Phase I Area

Figure 11

Drift Thickness

LEGEND

—30— Drift Thickness Contour (interval 10 metres)



SOURCES OF INFORMATION

Drift Thickness after:

Feenstra, B.H., 1982.
Drift Thickness of the Niagara and Niagara-on-the-Lake Area, Southern Ontario. Ontario Geological Survey Preliminary Map P.537 Rev., Drift Thickness Series, Scale 1:50,000.

Feenstra, B.H. and M. Troper, 1982.
Drift Thickness of the Welland-Fort Erie Area, Southern Ontario. Ontario Geological Survey Preliminary Map P.2486, Drift Thickness Series, Scale 1:50,000.

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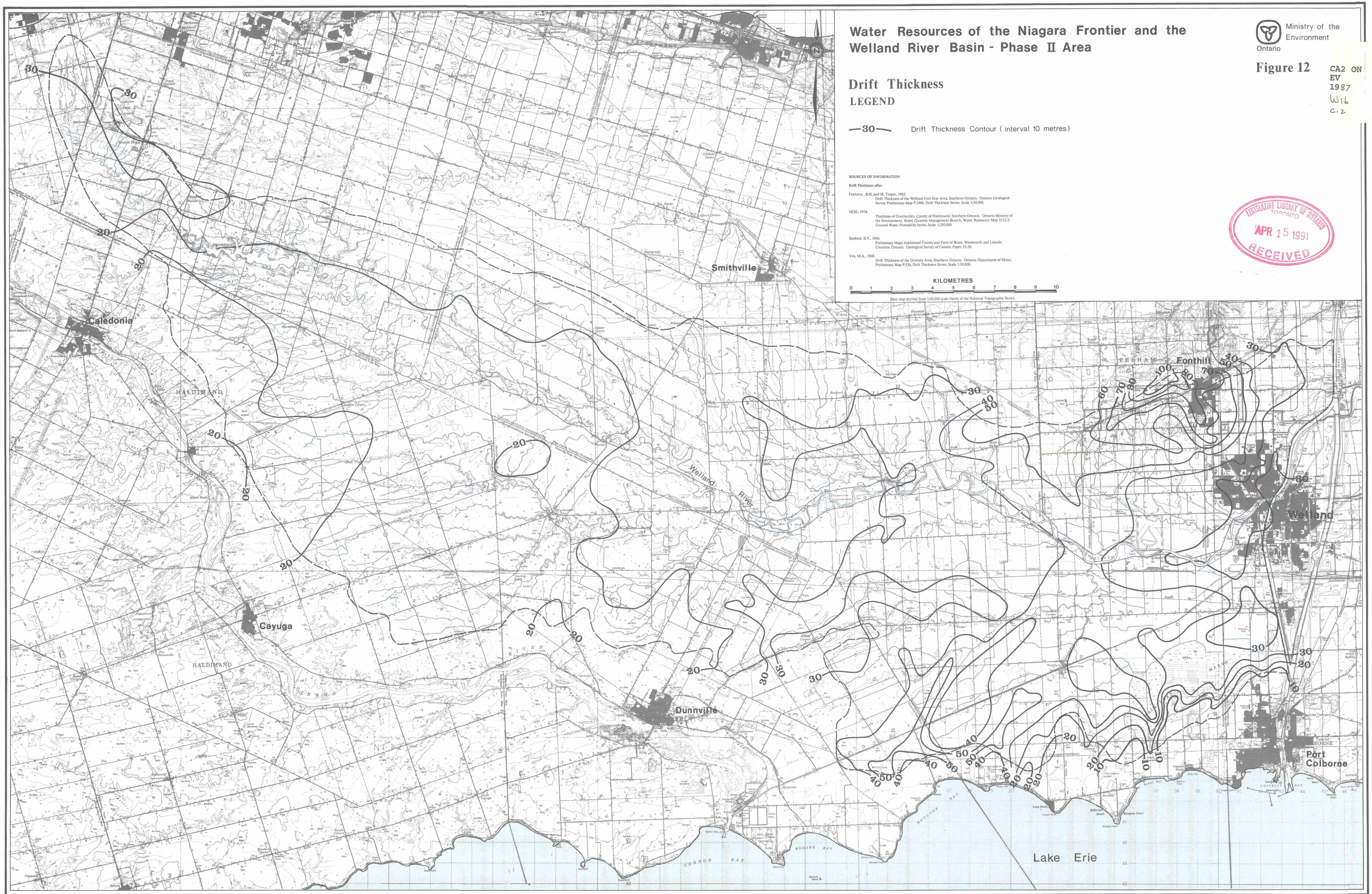

Water Resources of the Niagara Frontier and the Welland River Basin - Phase II Area

Ministry of the Environment
Ontario

Figure 12

CA2 ON
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Drift Thickness

LEGEND

—30— Drift Thickness Contour (interval 10 metres)

SOURCES OF INFORMATION

Drift Thickness after:

Feenstra , B.H. and M. Troper, 1982.
Drift Thickness of the Welland-Fort Erie Area, Southern Ontario. Ontario Geological Survey Preliminary Map P.2486, Drift Thickness Series, Scale 1:50,000.

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Vos, M.A., 1968.
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KILOMETRES

0 1 2 3 4 5 6 7 8 9 10

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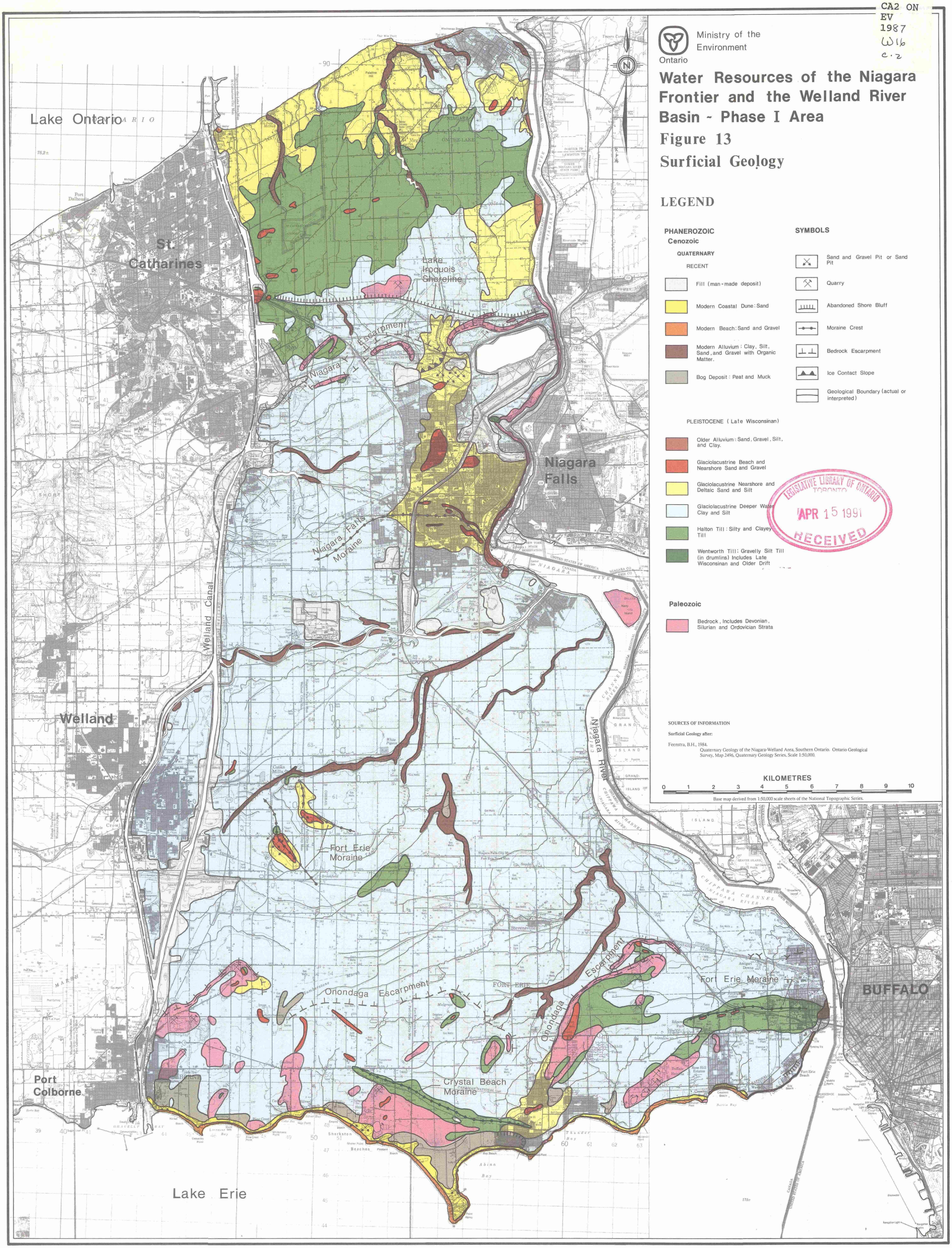
Water Resources of the Niagara Frontier and the Welland River Basin - Phase I Area

Figure 13

Surficial Geology



LEGEND

PHANEROZOIC
Cenozoic
QUATERNARY
RECENT

⬜	Fill (man-made deposit)
🟨	Modern Coastal Dune: Sand
🟧	Modern Beach: Sand and Gravel
🟫	Modern Alluvium: Clay, Silt, Sand, and Gravel with Organic Matter.
▨	Bog Deposit: Peat and Muck

PLEISTOCENE (Late Wisconsinan)

🟫	Older Alluvium: Sand, Gravel, Silt, and Clay.
🟥	Glaciolacustrine Beach and Nearshore Sand and Gravel
🟨	Glaciolacustrine Nearshore and Deltaic Sand and Silt
🟦	Glaciolacustrine Deeper Water Clay and Silt
🟩	Halton Till: Silty and Clayey Till
🟩	Wentworth Till: Gravelly Silt Till (in drumlins) Includes Late Wisconsinan and Older Drift

Paleozoic

🟪	Bedrock, Includes Devonian, Silurian and Ordovician Strata

SYMBOLS

⚒	Sand and Gravel Pit or Sand Pit
⚒	Quarry
⊥⊥⊥⊥	Abandoned Shore Bluff
●—●	Moraine Crest
⊥ ⊥	Bedrock Escarpment
▲▲	Ice Contact Slope
—	Geological Boundary (actual or interpreted)

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SOURCES OF INFORMATION

Surficial Geology after:

Feenstra, B.H., 1984.
Quaternary Geology of the Niagara-Welland Area, Southern Ontario. Ontario Geological Survey, Map 2496, Quaternary Geology Series, Scale 1:50,000.

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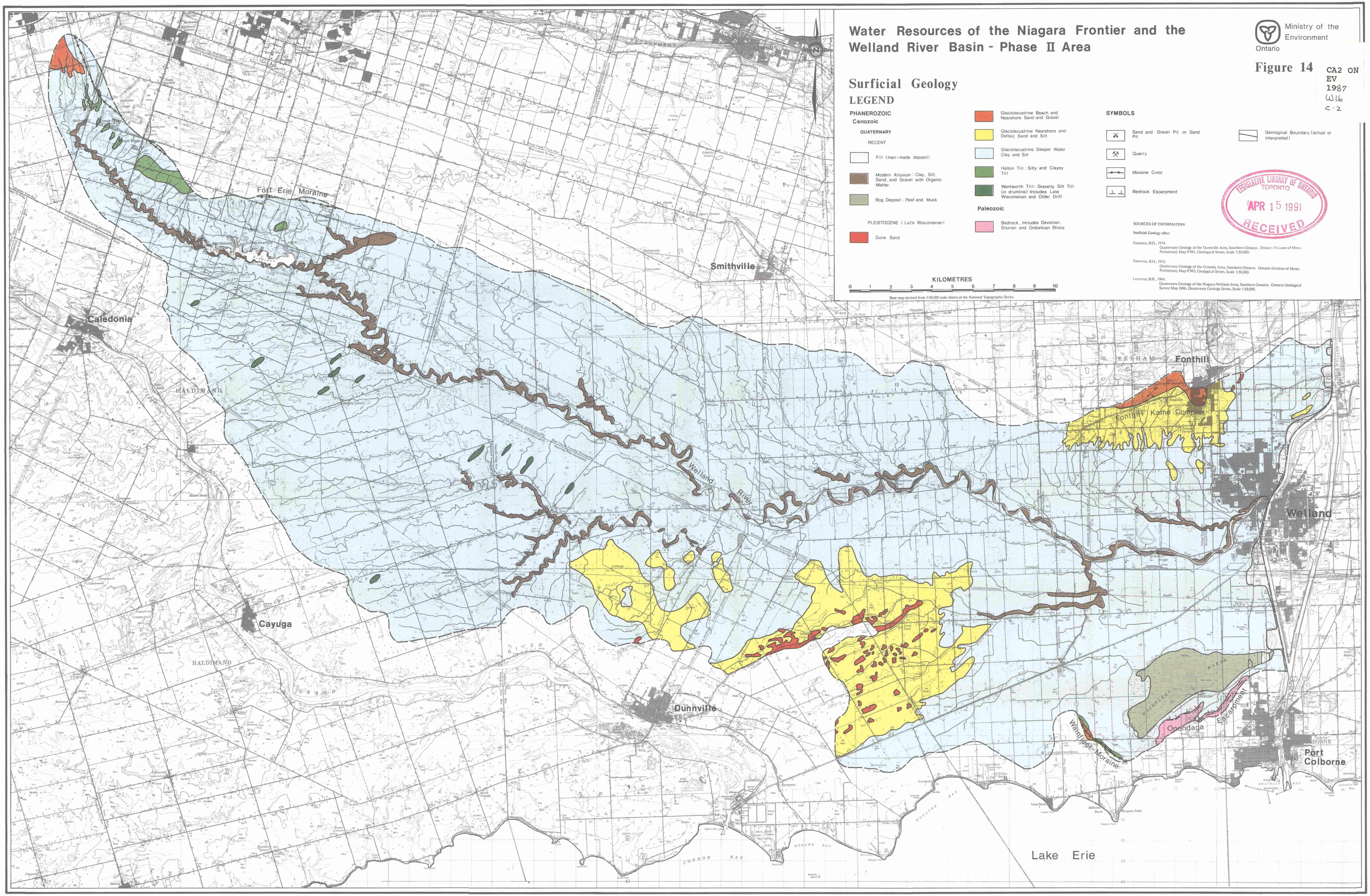

Water Resources of the Niagara Frontier and the Welland River Basin - Phase II Area

Ministry of the Environment
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Figure 14

CA2 ON
EV
1987
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Surficial Geology

LEGEND

PHANEROZOIC
Cenozoic
QUATERNARY
RECENT

⬜	Fill (man-made deposit)
🟫	Modern Alluvium: Clay, Silt, Sand, and Gravel with Organic Matter.
▨	Bog Deposit: Peat and Muck

PLEISTOCENE (Late Wisconsinan)

🟥	Dune Sand
🟧	Glaciolacustrine Beach and Nearshore Sand and Gravel
🟨	Glaciolacustrine Nearshore and Deltaic Sand and Silt
🟦	Glaciolacustrine Deeper Water Clay and Silt
🟩	Halton Till: Silty and Clayey Till
🟩	Wentworth Till: Gravelly Silt Till (in drumlins) Includes Late Wisconsinan and Older Drift

Paleozoic

🟪	Bedrock, Includes Devonian, Silurian and Ordovician Strata

SYMBOLS

⚒	Sand and Gravel Pit or Sand Pit
⚒	Quarry
—•—•—	Moraine Crest
⊥ ⊥	Bedrock Escarpment
▭	Geological Boundary (actual or interpreted)

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SOURCES OF INFORMATION

Surficial Geology after:

Feenstra, B.H., 1974.
Quaternary Geology of the Dunnville Area, Southern Ontario. Ontario Division of Mines, Preliminary Map P.981, Geological Series, Scale 1:50,000.

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KILOMETRES
0 1 2 3 4 5 6 7 8 9 10

Base map derived from 1:50,000 scale sheets of the National Topographic Series.

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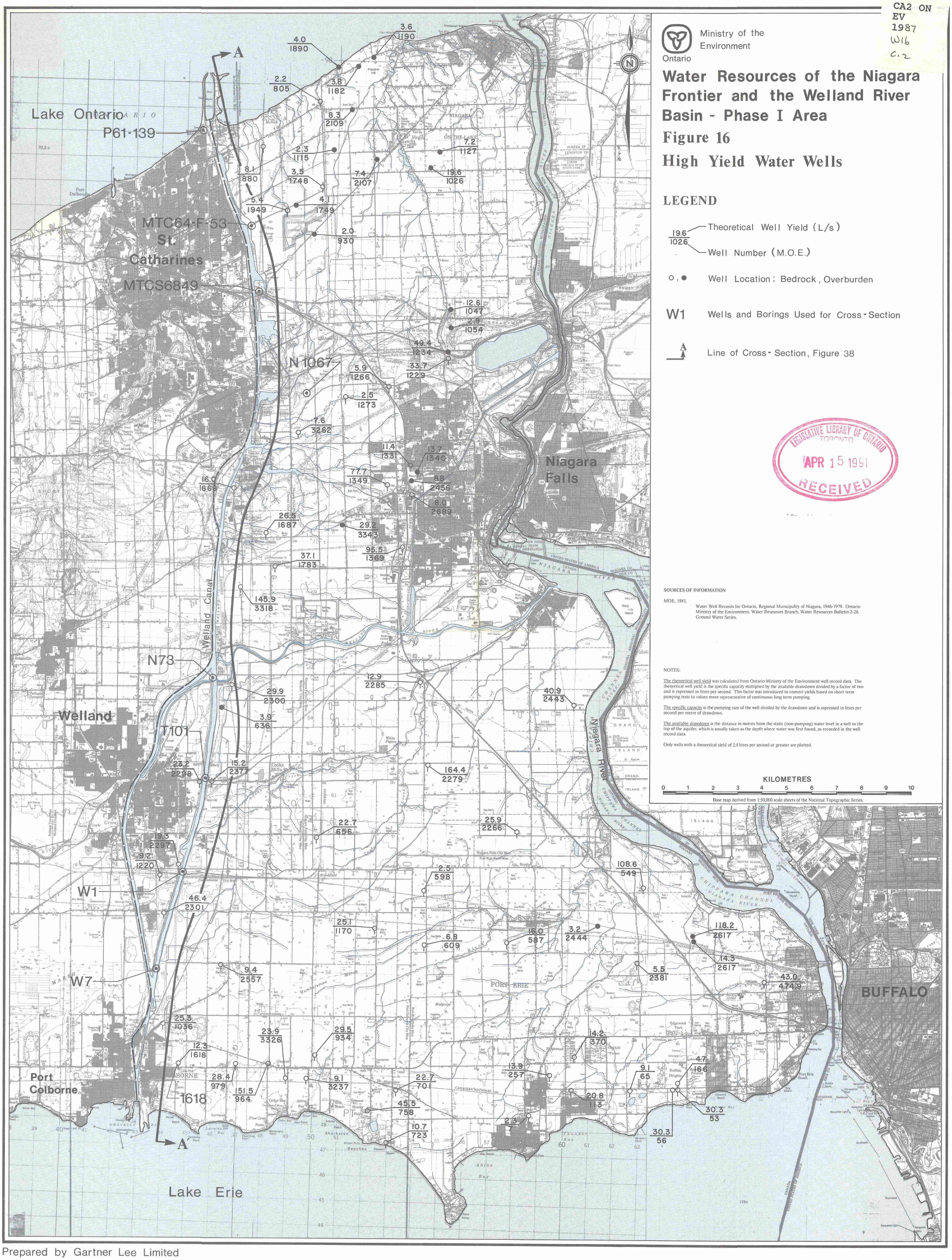
Water Resources of the Niagara Frontier and the Welland River Basin - Phase I Area

Figure 16

High Yield Water Wells



LEGEND

19.6 — Theoretical Well Yield (L/s)
1026 — Well Number (M.O.E.)

○, ● Well Location; Bedrock, Overburden

W1 Wells and Borings Used for Cross-Section

A Line of Cross-Section, Figure 38

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SOURCES OF INFORMATION

MOE, 1981.
Water Well Records for Ontario, Regional Municipality of Niagara, 1946-1979. Ontario Ministry of the Environment, Water Resources Branch, Water Resources Bulletin 2-28, Ground Water Series.

NOTES:

The theoretical well yield was calculated from Ontario Ministry of the Environment well record data. The theoretical well yield is the specific capacity multiplied by the available drawdown divided by a factor of two and is expressed in litres per second. This factor was introduced to convert yields based on short term pumping tests to values more representative of continuous long term pumping.

The specific capacity is the pumping rate of the well divided by the drawdown and is expressed in litres per second per metre of drawdown.

The available drawdown is the distance in metres from the static (non-pumping) water level in a well to the top of the aquifer, which is usually taken as the depth where water was first found, as recorded in the well record data.

Only wells with a theoretical yield of 2.0 litres per second or greater are plotted.

KILOMETRES
0 1 2 3 4 5 6 7 8 9 10

Base map derived from 1:50,000 scale sheets of the National Topographic Series.

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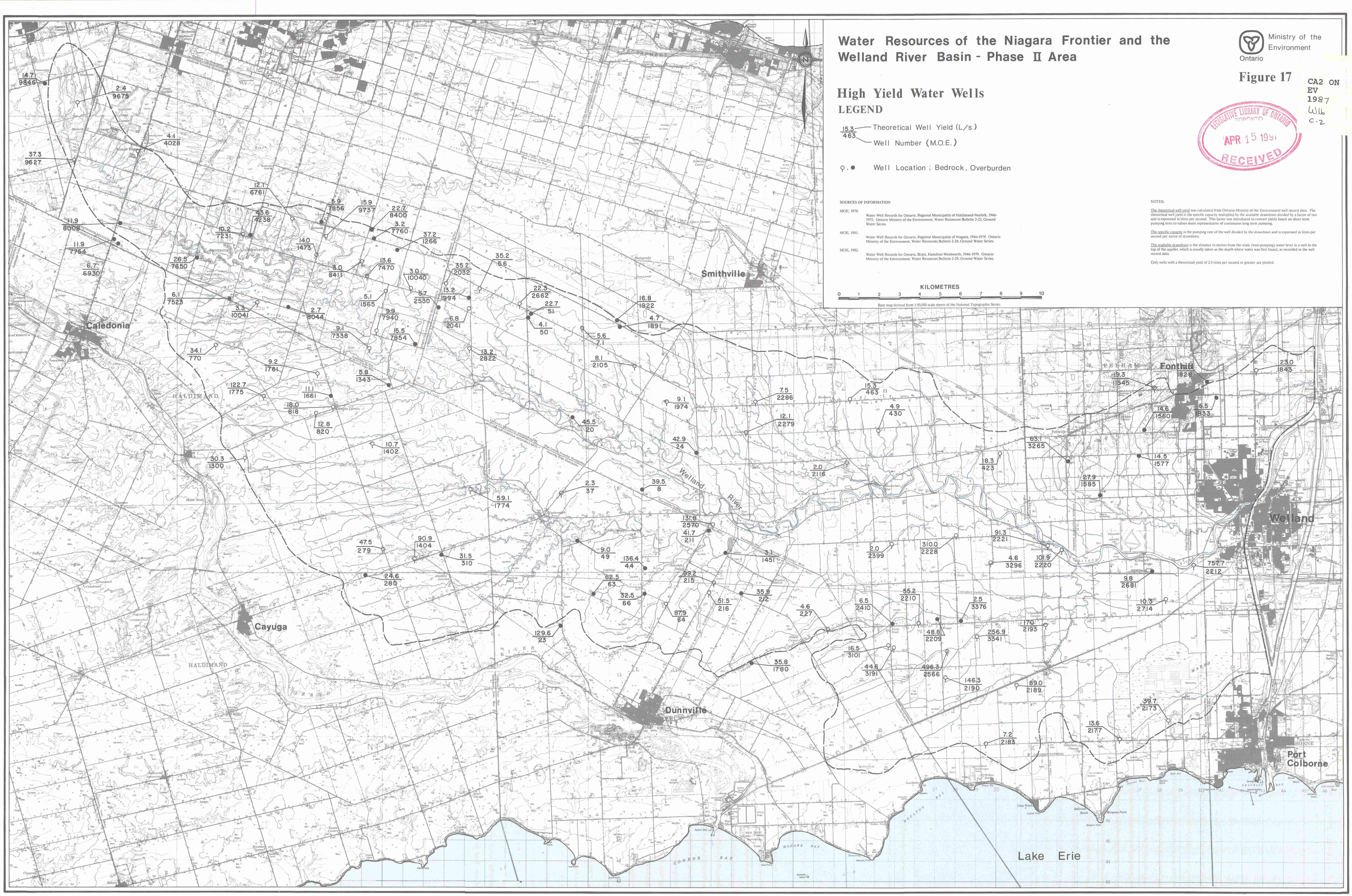
Figure 17



High Yield Water Wells

LEGEND

15.3 — Theoretical Well Yield (L/s)
463 — Well Number (M.O.E.)

○, ● Well Location ; Bedrock , Overburden

SOURCES OF INFORMATION

MOE, 1978.
Water Well Records for Ontario, Regional Municipality of Haldimand-Norfolk, 1946-1975. Ontario Ministry of the Environment, Water Resources Bulletin 2-23, Ground Water Series.

MOE, 1981.
Water Well Records for Ontario, Regional Municipality of Niagara, 1946-1979. Ontario Ministry of the Environment, Water Resources Bulletin 2-28, Ground Water Series.

MOE, 1982.
Water Well Records for Ontario, Brant, Hamilton-Wentworth, 1946-1979. Ontario Ministry of the Environment, Water Resources Bulletin 2-29, Ground Water Series.

KILOMETRES
0 1 2 3 4 5 6 7 8 9 10

Base map derived from 1:50,000 scale sheets of the National Topographic Series.

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The theoretical well yield was calculated from Ontario Ministry of the Environment well record data. The theoretical well yield is the specific capacity multiplied by the available drawdown divided by a factor of two and is expressed in litres per second. This factor was introduced to convert yields based on short term pumping tests to values more representative of continuous long term pumping.

The specific capacity is the pumping rate of the well divided by the drawdown and is expressed in litres per second per metre of drawdown.

The available drawdown is the distance in metres from the static (non-pumping) water level in a well to the top of the aquifer, which is usually taken as the depth where water was first found, as recorded in the well record data.

Only wells with a theoretical yield of 2.0 litres per second or greater are plotted.

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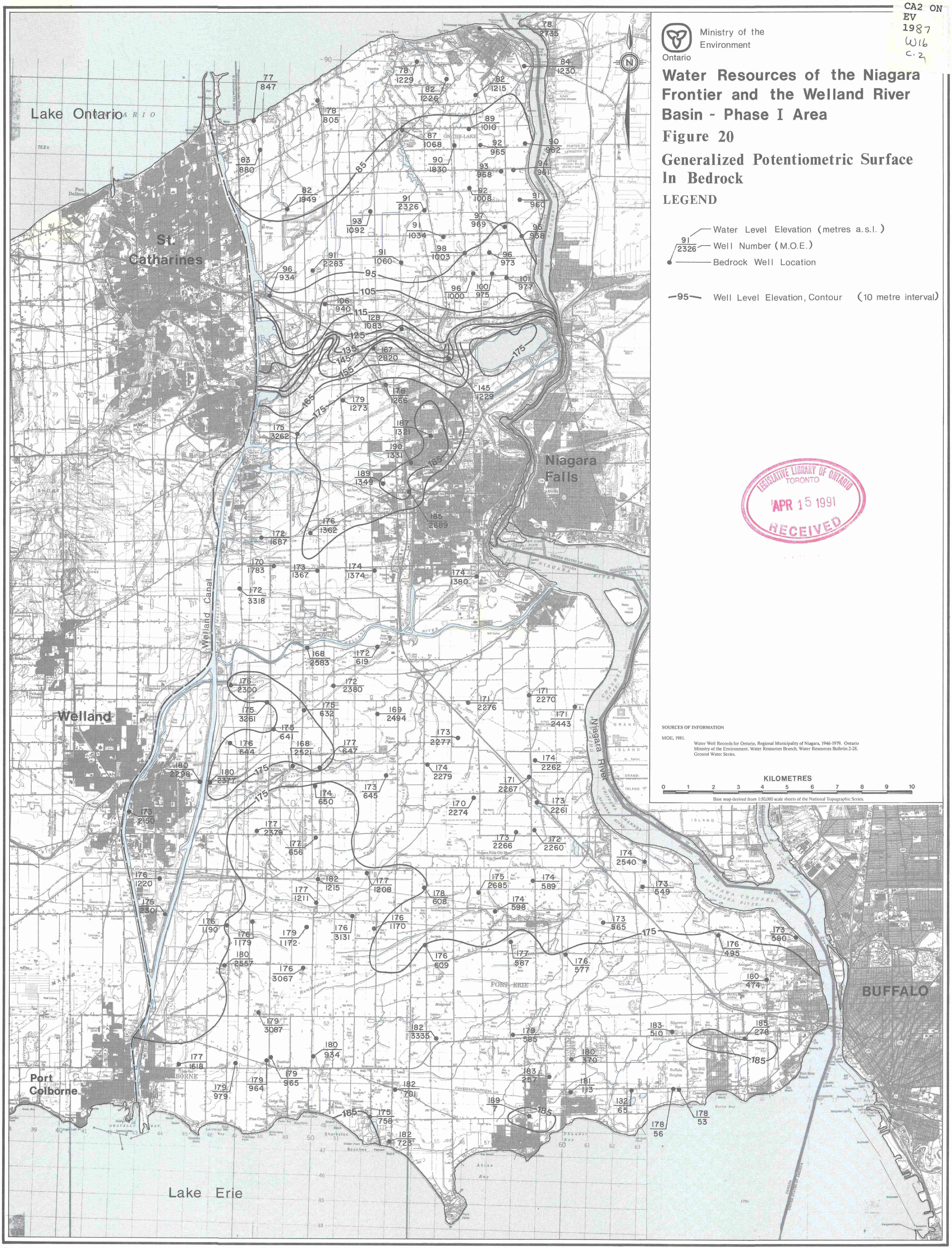
Water Resources of the Niagara Frontier and the Welland River Basin - Phase I Area

Figure 20

Generalized Potentiometric Surface In Bedrock

LEGEND

91	Water Level Elevation (metres a.s.l.)
2326	Well Number (M.O.E.)
●	Bedrock Well Location
—95—	Well Level Elevation, Contour (10 metre interval)



SOURCES OF INFORMATION

MOE, 1981.
Water Well Records for Ontario, Regional Municipality of Niagara, 1946-1979. Ontario Ministry of the Environment, Water Resources Branch, Water Resources Bulletin 2-28, Ground Water Series.

KILOMETRES
0 1 2 3 4 5 6 7 8 9 10

Base map derived from 1:50,000 scale sheets of the National Topographic Series.

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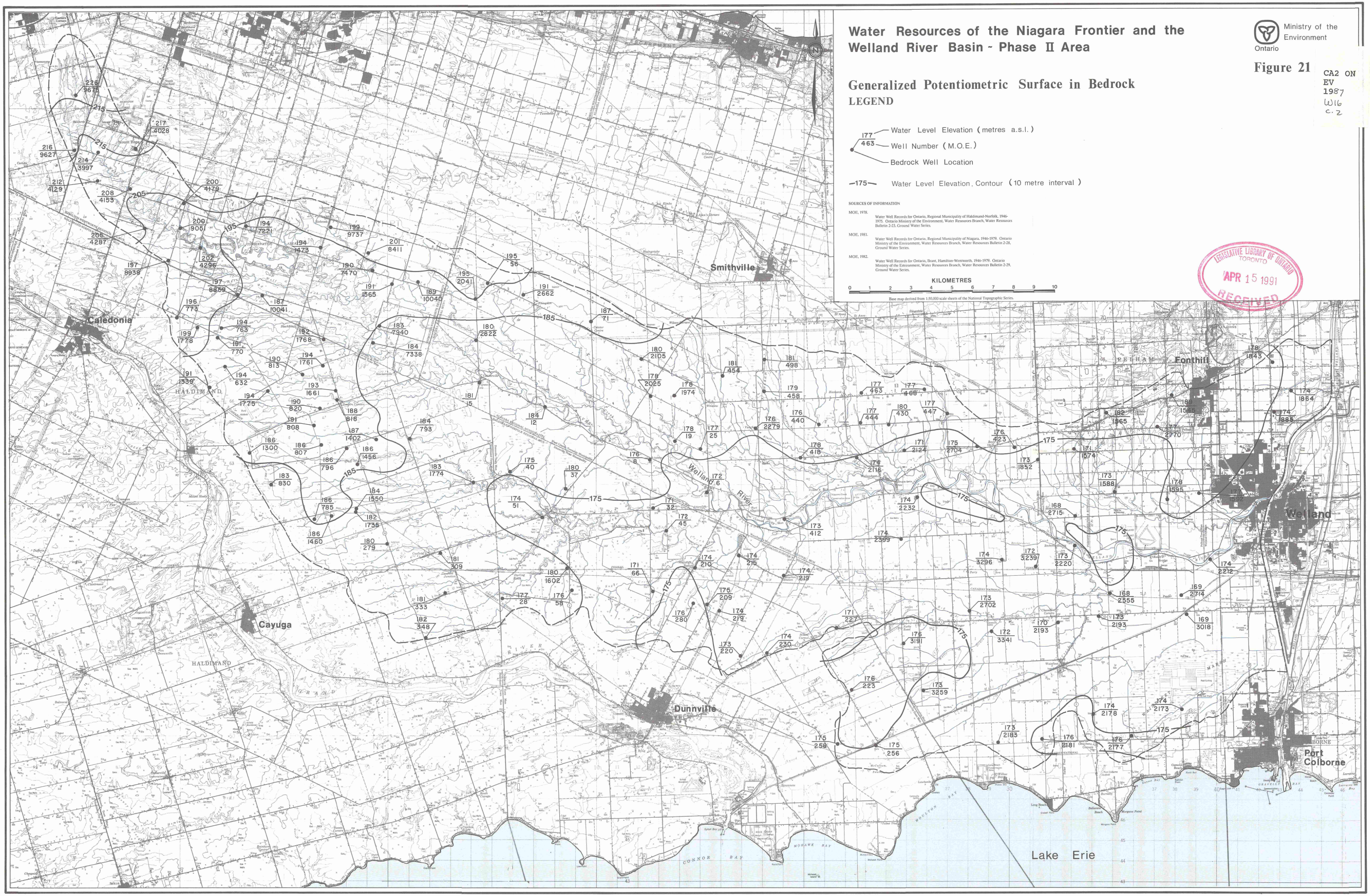

Water Resources of the Niagara Frontier and the Welland River Basin - Phase II Area

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Figure 21

Generalized Potentiometric Surface in Bedrock

LEGEND

177 — Water Level Elevation (metres a.s.l.)
463 — Well Number (M.O.E.)
● — Bedrock Well Location

—175— Water Level Elevation, Contour (10 metre interval)

SOURCES OF INFORMATION

MOE, 1978.
Water Well Records for Ontario, Regional Municipality of Haldimand-Norfolk, 1946-1975. Ontario Ministry of the Environment, Water Resources Branch, Water Resources Bulletin 2-23, Ground Water Series.

MOE, 1981.
Water Well Records for Ontario, Regional Municipality of Niagara, 1946-1979. Ontario Ministry of the Environment, Water Resources Branch, Water Resources Bulletin 2-28, Ground Water Series.

MOE, 1982.
Water Well Records for Ontario, Brant, Hamilton-Wentworth, 1946-1979. Ontario Ministry of the Environment, Water Resources Branch, Water Resources Bulletin 2-29, Ground Water Series.

KILOMETRES
0 1 2 3 4 5 6 7 8 9 10

Base map derived from 1:50,000 scale sheets of the National Topographic Series.

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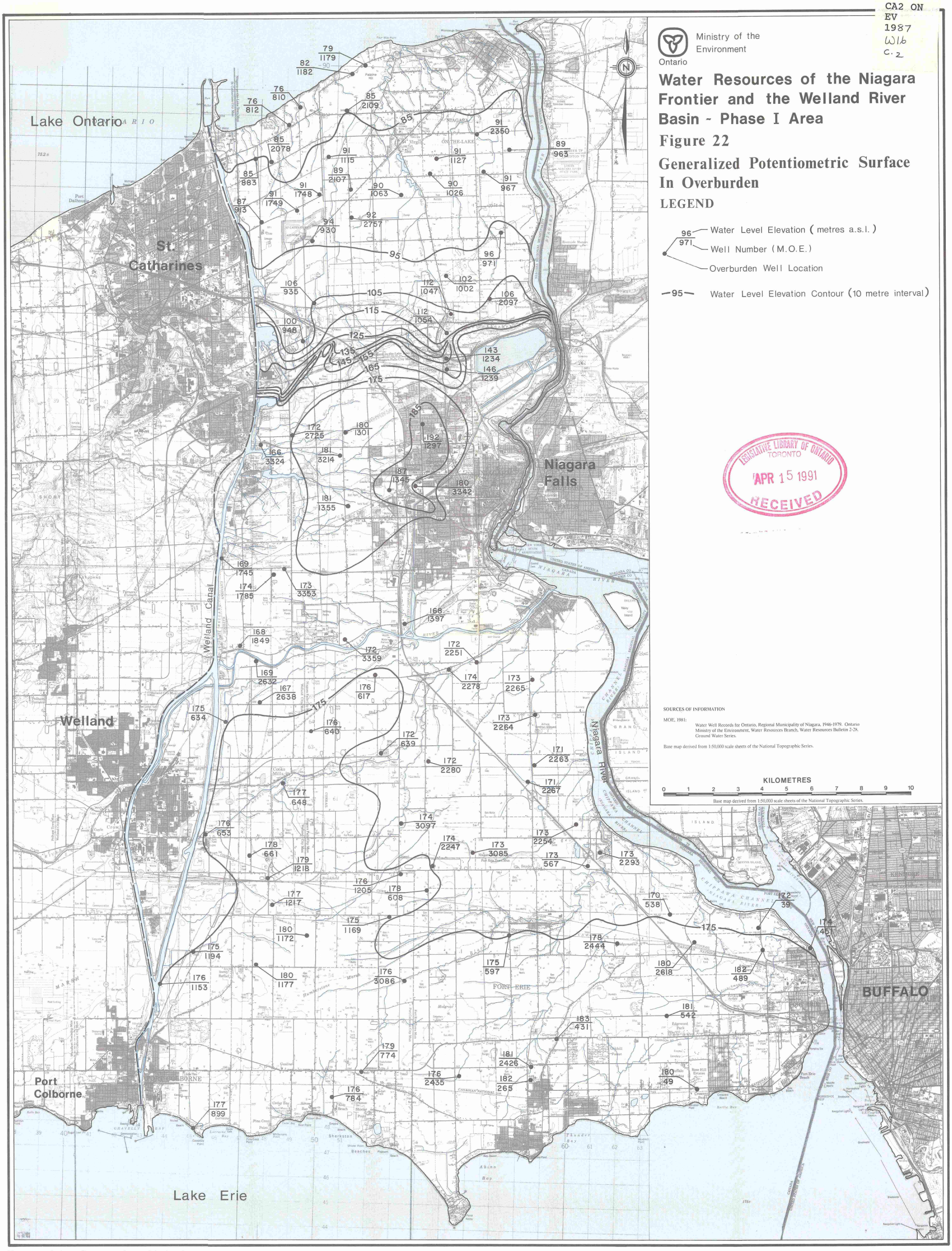
Water Resources of the Niagara Frontier and the Welland River Basin - Phase I Area

Figure 22

Generalized Potentiometric Surface In Overburden

LEGEND

96 — Water Level Elevation (metres a.s.l.)
971 — Well Number (M.O.E.)
Overburden Well Location
—95— Water Level Elevation Contour (10 metre interval)



SOURCES OF INFORMATION

MOE, 1981:
Water Well Records for Ontario, Regional Municipality of Niagara, 1946-1979. Ontario Ministry of the Environment, Water Resources Branch, Water Resources Bulletin 2-28, Ground Water Series.

Base map derived from 1:50,000 scale sheets of the National Topographic Series.

Base map derived from 1:50,000 scale sheets of the National Topographic Series.

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Figure 23

Generalized Potentiometric Surface In Overburden

LEGEND

176 — Water Level Elevation (metres a.s.l.)
440 — Well Number (M.O.E.)
● — Overburden Well Location

—175— Water Level Elevation, Contour (10 metre interval)

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SOURCES OF INFORMATION

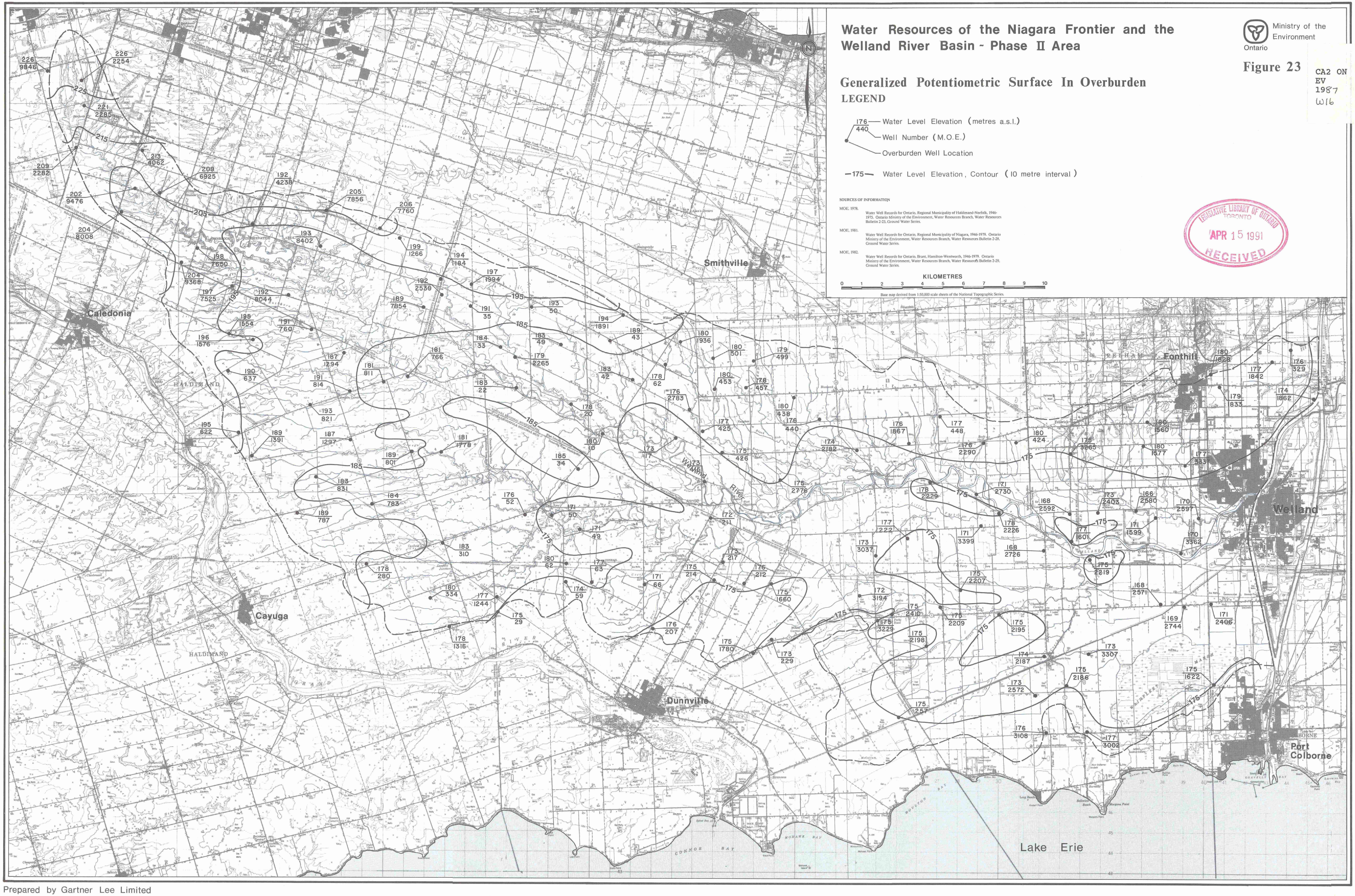
MOE, 1978.
Water Well Records for Ontario, Regional Municipality of Haldimand-Norfolk, 1946-1975. Ontario Ministry of the Environment, Water Resources Branch, Water Resources Bulletin 2-23, Ground Water Series.

MOE, 1981.
Water Well Records for Ontario, Regional Municipality of Niagara, 1946-1979. Ontario Ministry of the Environment, Water Resources Branch, Water Resources Bulletin 2-28, Ground Water Series.

MOE, 1982.
Water Well Records for Ontario, Brant, Hamilton-Wentworth, 1946-1979. Ontario Ministry of the Environment, Water Resources Branch, Water Resources Bulletin 2-29, Ground Water Series.

KILOMETRES
0 1 2 3 4 5 6 7 8 9 10

Base map derived from 1:50,000 scale sheets of the National Topographic Series.



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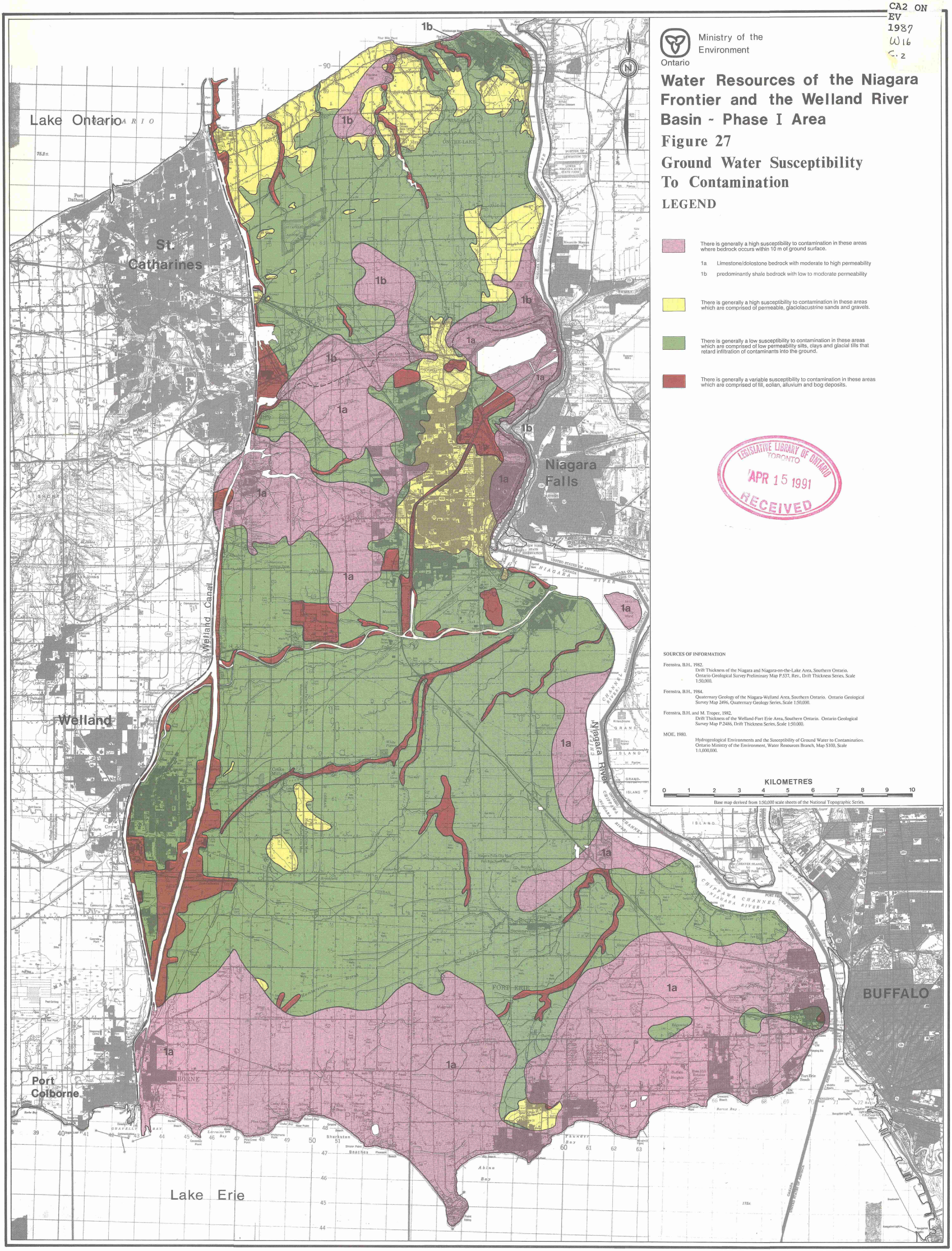

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Water Resources of the Niagara Frontier and the Welland River Basin - Phase I Area

Figure 27

Ground Water Susceptibility To Contamination

LEGEND

🟪 There is generally a high susceptibility to contamination in these areas where bedrock occurs within 10 m of ground surface.

1a	Limestone/dolostone bedrock with moderate to high permeability
1b	predominantly shale bedrock with low to moderate permeability

🟨 There is generally a high susceptibility to contamination in these areas which are comprised of permeable, glaciolacustrine sands and gravels.

🟩 There is generally a low susceptibility to contamination in these areas which are comprised of low permeability silts, clays and glacial tills that retard infiltration of contaminants into the ground.

🟥 There is generally a variable susceptibility to contamination in these areas which are comprised of fill, eolian, alluvium and bog deposits.

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SOURCES OF INFORMATION

Feenstra, B.H., 1982.
Drift Thickness of the Niagara and Niagara-on-the-Lake Area, Southern Ontario. Ontario Geological Survey Preliminary Map P.537, Rev., Drift Thickness Series, Scale 1:50,000.

Feenstra, B.H., 1984.
Quaternary Geology of the Niagara-Welland Area, Southern Ontario. Ontario Geological Survey Map 2496, Quaternary Geology Series, Scale 1:50,000.

Feenstra, B.H. and M. Troper, 1982.
Drift Thickness of the Welland-Fort Erie Area, Southern Ontario. Ontario Geological Survey Map P.2486, Drift Thickness Series, Scale 1:50.000.

MOE, 1980.
Hydrogeological Environments and the Susceptibility of Ground Water to Contamination. Ontario Ministry of the Environment, Water Resources Branch, Map S100, Scale 1:1,000,000.

KILOMETRES
0 1 2 3 4 5 6 7 8 9 10

Base map derived from 1:50,000 scale sheets of the National Topographic Series.

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Figure 28

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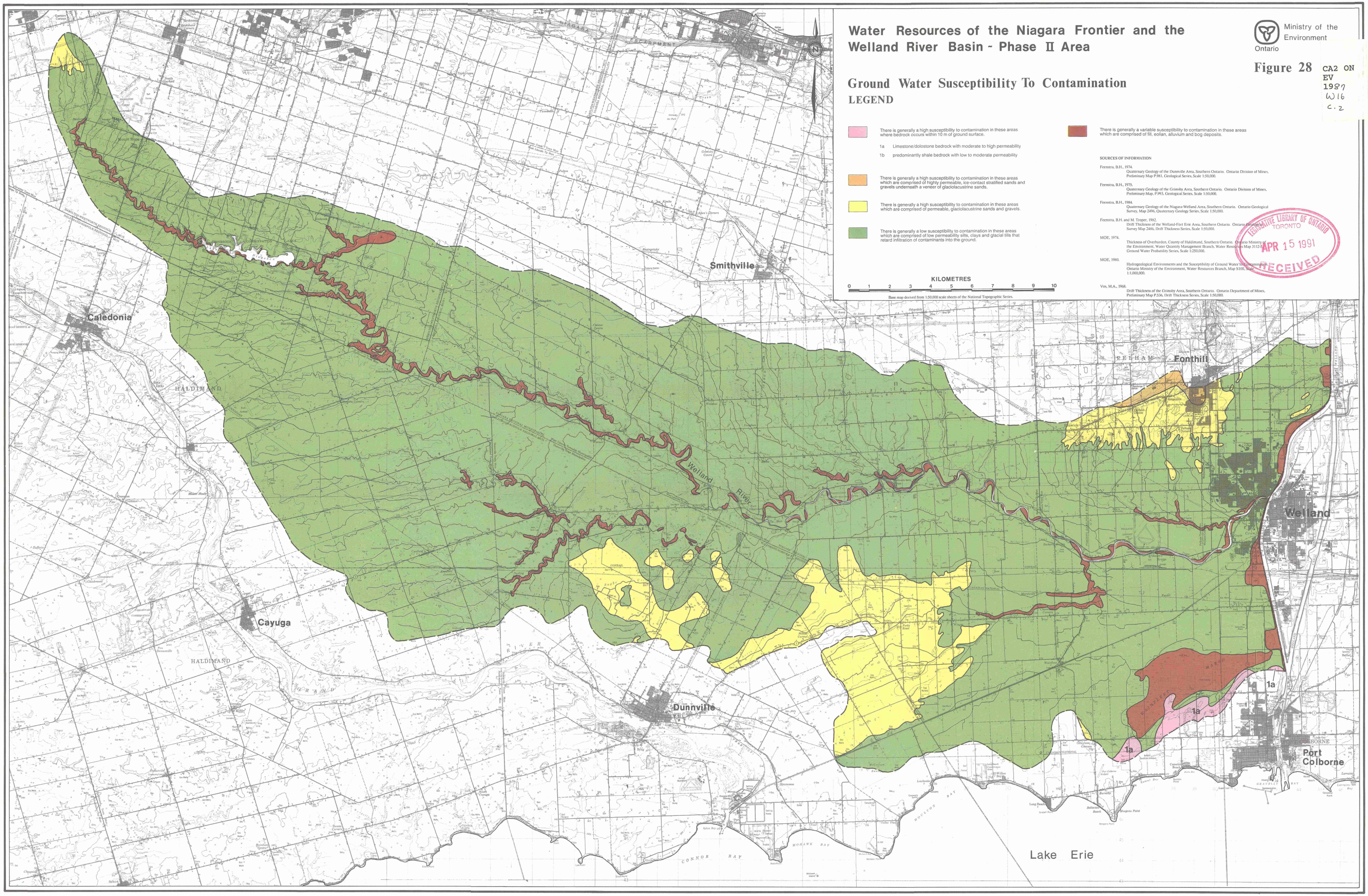
Ground Water Susceptibility To Contamination



LEGEND

🟪 There is generally a high susceptibility to contamination in these areas where bedrock occurs within 10 m of ground surface.

1a Limestone/dolostone bedrock with moderate to high permeability

1b predominantly shale bedrock with low to moderate permeability

🟧 There is generally a high susceptibility to contamination in these areas which are comprised of highly permeable, ice-contact stratified sands and gravels underneath a veneer of glaciolacustrine sands.

🟨 There is generally a high susceptibility to contamination in these areas which are comprised of permeable, glaciolacustrine sands and gravels.

🟩 There is generally a low susceptibility to contamination in these areas which are comprised of low permeability silts, clays and glacial tills that retard infiltration of contaminants into the ground.

🟫 There is generally a variable susceptibility to contamination in these areas which are comprised of fill, eolian, alluvium and bog deposits.

KILOMETRES

0 1 2 3 4 5 6 7 8 9 10

Base map derived from 1:50,000 scale sheets of the National Topographic Series.

SOURCES OF INFORMATION

Feenstra, B.H., 1974.
Quaternary Geology of the Dunnville Area, Southern Ontario. Ontario Division of Mines, Preliminary Map P.981, Geological Series, Scale 1:50,000.

Feenstra, B.H., 1975.
Quaternary Geology of the Grimsby Area, Southern Ontario. Ontario Division of Mines, Preliminary Map, P.993, Geological Series, Scale 1:50,000.

Feenstra, B.H., 1984.
Quaternary Geology of the Niagara-Welland Area, Southern Ontario. Ontario Geological Survey, Map 2496, Quaternary Geology Series, Scale 1:50,000.

Feenstra, B.H. and M. Troper, 1982.
Drift Thickness of the Welland-Fort Erie Area, Southern Ontario. Ontario Geological Survey Map 2486, Drift Thickness Series, Scale 1:50,000.

MOE, 1974.
Thickness of Overburden, County of Haldimand, Southern Ontario. Ontario Ministry of the Environment, Water Quantity Management Branch, Water Resources Map 3112-3, Ground Water Probability Series, Scale 1:250,000.

MOE, 1980.
Hydrogeological Environments and the Susceptibility of Ground Water to Contamination. Ontario Ministry of the Environment, Water Resources Branch, Map S100, Scale 1:1,000,000.

Vos, M.A., 1968.
Drift Thickness of the Grimsby Area, Southern Ontario. Ontario Department of Mines, Preliminary Map P.536, Drift Thickness Series, Scale 1:50,000.

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Water Resources of the Niagara Frontier and the Welland River Basin - Phase I Area

Figure 31

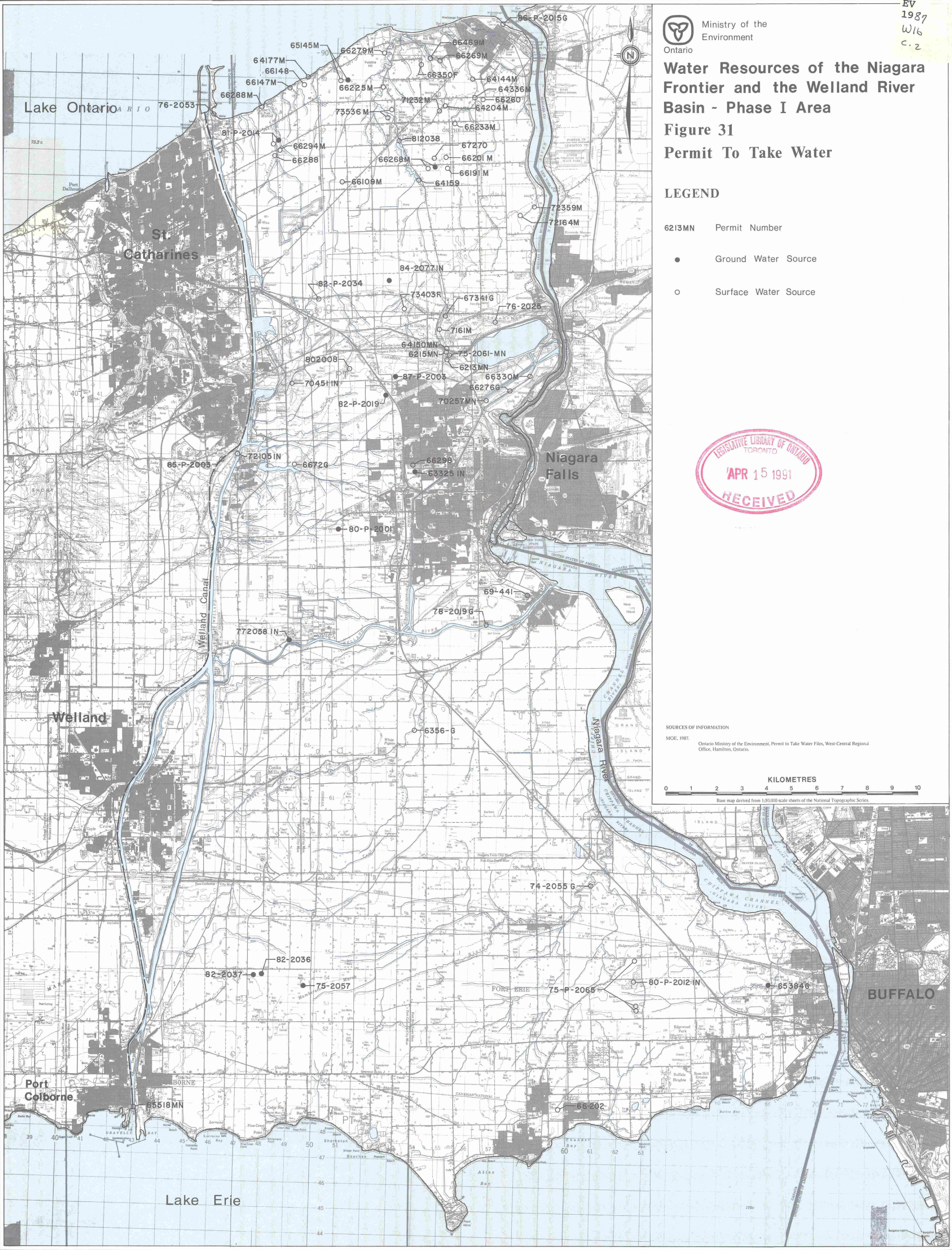
Permit To Take Water

LEGEND

6213MN Permit Number

● Ground Water Source

○ Surface Water Source



SOURCES OF INFORMATION

MOE, 1987.
Ontario Ministry of the Environment, Permit to Take Water Files, West-Central Regional Office, Hamilton, Ontario.

KILOMETRES
0 1 2 3 4 5 6 7 8 9 10

Base map derived from 1:50,000 scale sheets of the National Topographic Series.

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Figure 32

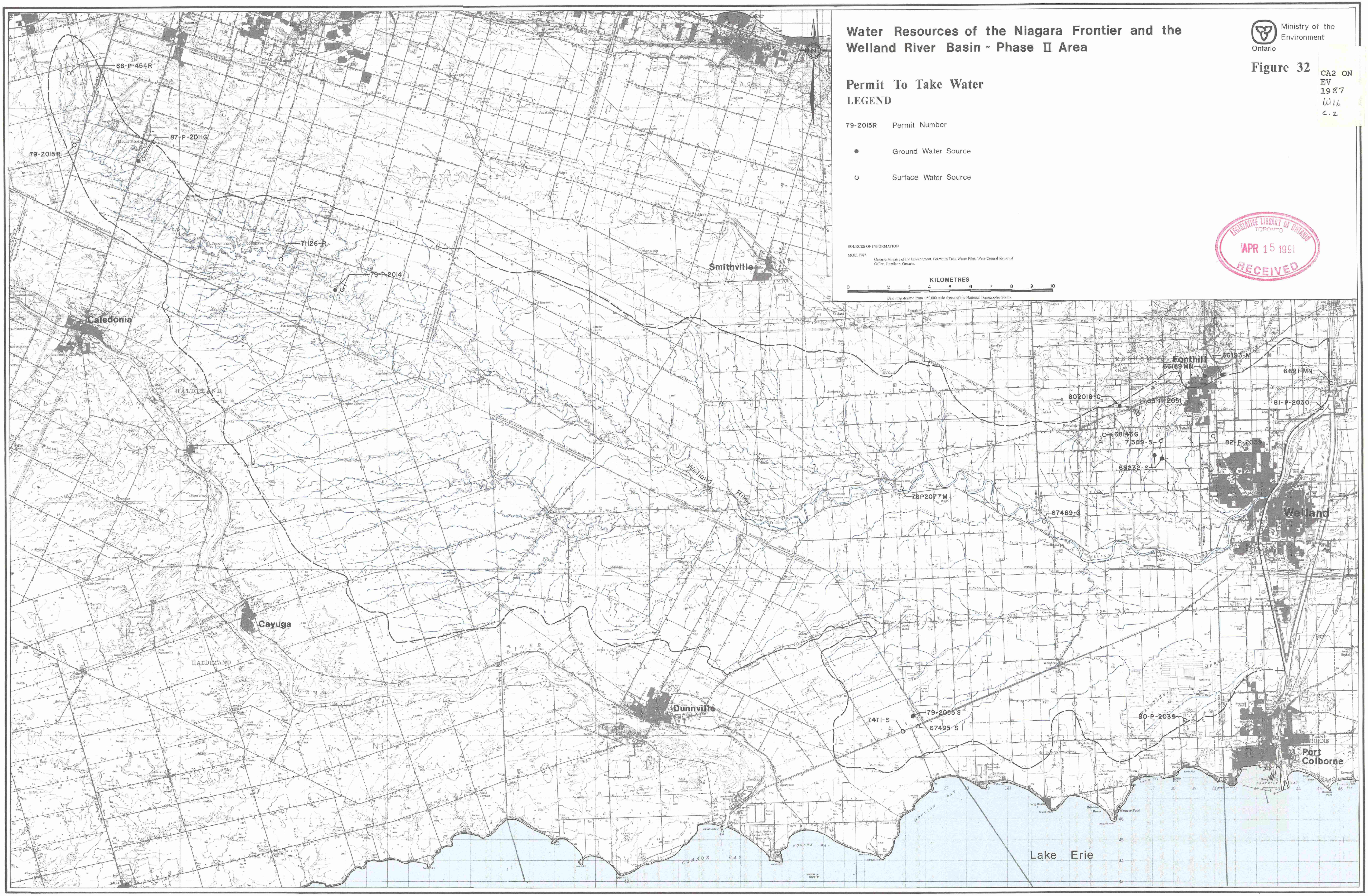
Permit To Take Water

LEGEND

79-2015R	Permit Number
●	Ground Water Source
○	Surface Water Source

SOURCES OF INFORMATION

MOE, 1987.
Ontario Ministry of the Environment, Permit to Take Water Files, West-Central Regional Office, Hamilton, Ontario.



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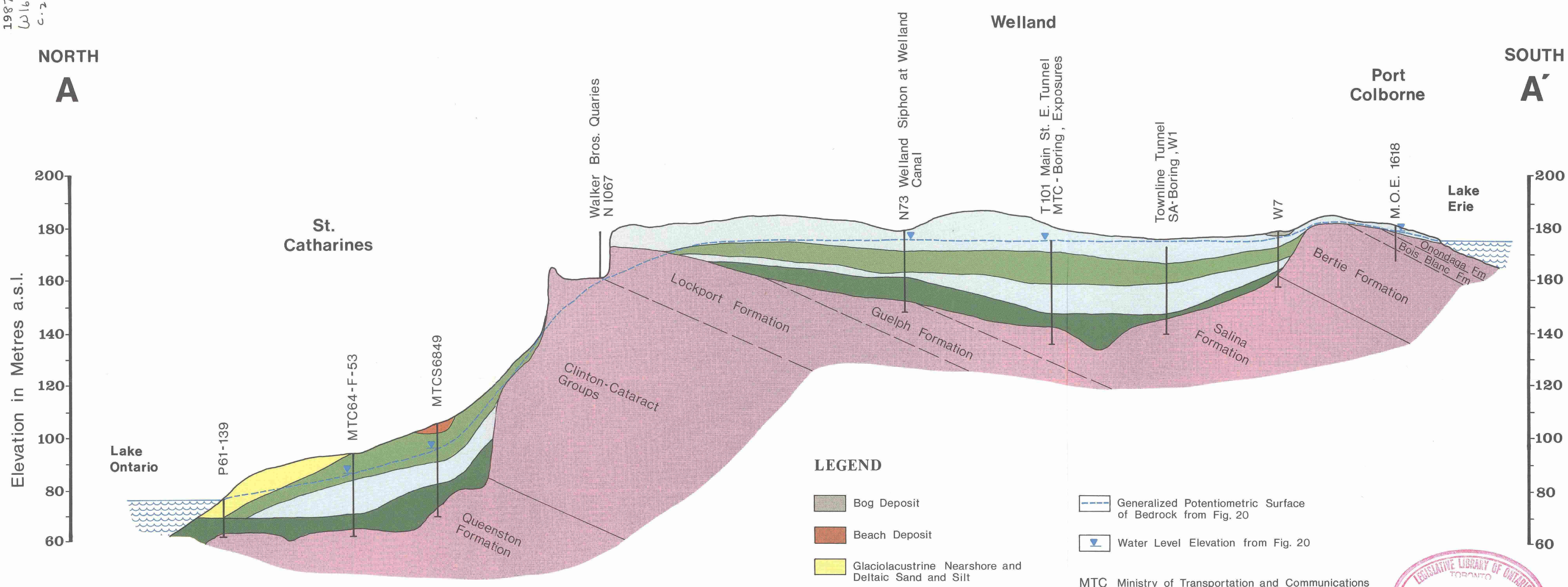

LEGEND

▨	Bog Deposit
▨	Beach Deposit
▨	Glaciolacustrine Nearshore and Deltaic Sand and Silt
▨	Glaciolacustrine Deeper Water Clay and Silt
▨	Halton Till
▨	Wentworth Till
▨	Bedrock
- - -	Generalized Potentiometric Surface of Bedrock from Fig. 20
▼	Water Level Elevation from Fig. 20
MTC	Ministry of Transportation and Communications
P	Peto Assoc. Ltd.
SA	St. Lawrence Seaway Authority
MOE	Ministry of the Environment
N	Feenstra 1981
W	Feenstra 1981

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Generalized Hydrogeological Cross Section Along The Welland Canal

Figure 36

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Horizontal Scale 1:100,000
Vertical Scale 1:1,250
Vertical Exaggeration X80

(after Feensta 1981 Figure 9)

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